United States Air Force
Scientific Advisory Board

Report on

Sustaining Air Force Aging Aircraft into the 21st Century

SAB-TR-11-01
1 August 2011

DISTRIBUTION AUTHORIZED
In accordance with AFI 61-204 and DODD 5230.24, Distribution Statement A, Approved for Public Release, Distribution Unlimited.

20120615402

This report is a product of the United States Air Force Scientific Advisory Board 2011 Summer Study on Sustaining Air Force Aging Aircraft into the 21st Century. Statements, opinions, recommendations, and conclusions contained in this report are those of the Study members and do not necessarily represent the official position of the United States Air Force or the Department of Defense.

United States Air Force
Scientific Advisory Board

Report on

Sustaining Air Force Aging Aircraft into the 21st Century

SAB-TR-11-01

1 August 2011

(This Page Intentionally Left Blank)

Foreword

According to the latest Department of Defense Aircraft Procurement Plan (Fiscal Years 2012-2041), the United States Air Force (USAF) will operate many of its aircraft well beyond their original design service lives. The USAF Scientific Advisory Board (SAB) was tasked to identify investments that will contribute to the safety, availability, and capability for those fleets that are approaching their design service lives.

This report presents the major findings from the SAB Study on Sustaining Air Force Aging Aircraft (SAA) into the 21st Century. As many of its fleets of legacy aircraft types are kept in service well beyond their planned services lives (sometimes in age, sometimes in usage, sometimes both), the Air Force (AF) faces numerous engineering and resource challenges for the continued, cost-effective sustainment of those aging systems. This report details the recommendations made by the Study to best position the Air Force for meeting those challenges.

The Study Panel visited a cross section of commercial and military USAF aircraft sustainment facilities and received high quality briefings from a broad range of entities involved with the current and future sustainment of the USAF's fleet of aging aircraft. Briefings were received from four companies performing sustainment operations and sustainment research and development relevant to aging aircraft (Boeing, General Atomics, Lockheed-Martin, and Northrop Grumman) as well as from the (AF) Research Laboratory (Materials and Manufacturing, Propulsion, and Air Vehicles Directorates and the Office of Scientific Research). The Panel also heard from organizations outside the USAF including the Naval Research Laboratory, Naval Air Systems Command, National Air and Space Administration, Federal Aviation Administration, and Delta Airlines—all of which have current aircraft sustainment, technology, and/or aircraft sustainment process oversight activities. The Panel benefited from hearing from most AF Major Commands (sustainment, requirements, and planning), including Air Combat Command, Air Force Materiel Command, Air Mobility Command, AF Global Strike Command, AF Special Operations Command, and the Air Education and Training Command. Also, the Study Team made fact-finding visits to the three AF Materiel Command (AFMC) Air Logistics Centers and the Air Force Global Logistics Support Center. Visits with aircraft flight line maintainers at the 388th and 1st Fighter Wings, at Hill and Langley Air Force Bases, provided useful insights.

The Study Team included members from academia, Federally Funded Research and Development Centers, and industry, along with advisors from the AF Materiel Command (AFMC Directorate of Logistics and AF Research Laboratory's Materials and Manufacturing Directorate), all representing a diverse set of backgrounds. The undersigned acknowledge the outstanding efforts put forth by the members of the Study Team, the volunteer Executive Officers, and AF SAB Secretariat members who all put in long hours supporting this Study.

Alan C. Eckbreth
Dr. Alan C. Eckbreth
SAA Study Chair

Charles R. Saff
Mr. Charles R. Saff
SAA Study Vice Chair

(This Page Intentionally Left Blank)

Executive Summary

Introduction

The United States Air Force (USAF) is going through a period of reduced recapitalization, coupled with program development delays, that is going to require current fleets to have lives extended ten to thirty years into the future if the current force structure is to be maintained. The effort required to extend the operation of fleets already approaching their design service lives is going to increase as failure modes beyond those identified in design begin to become more prevalent. These failure modes are due more to age than to usage or fatigue and they occur more rapidly when the aircraft is on the ground than when it is in flight. So reducing usage will not improve these life-limiting failure modes.

The Air Force Scientific Advisory Board was asked to explore potential technical solutions for the sustainment of these aging fleets into the middle part of the 21st Century. The Study Panel was asked to identify specific aircraft systems, in addition to structures and engines, that contribute to safety, availability, and effectiveness for aging aircraft; examine commercial practices in airlines, air freight services, and other industries, and evaluate how they might be applied to meet Air Force needs; and identify technology needs and technology approaches that can be applied or developed to extend life or ease maintenance of these aircraft systems, while facilitating future adaptations and performance enhancements of the aircraft.

There were elements of the task set before the Study that were not considered. These included a review or revision of priorities of the Fleet Viability Board (FVB), review and revisions of the upgrades planned for various Mission Design Series (MDS) aircraft, and recommendations of how the USAF should address the modernization needs for each MDS. It was determined by the Study that the FVB and the System Program Offices were so familiar with the aircraft, their histories, their current and planned maintenance and upgrade plans, that there was no benefit this Study could provide to the data and recommendations the USAF already has from these MDS experts.

Note: A related study[1] was conducted by the National Academy of Sciences contemporaneously with this Study. This Study was cognizant of and informed by portions of the National Academy of Sciences study.

---

1 National Research Council (Air Force Studies Board). "Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs."

Background

For purposes of this report, sustainment is defined as the combination of operations and maintenance (O&M) and modifications for upgraded performance. Maintenance includes repair, remanufacture, and component replacement (form, fit, function replacement due to obsolescence or Diminishing Manufacturing Sources). These efforts are funded under O&M funding (Department of Defense appropriation code 3400 funds). Upgrades for modernization and capability must be funded under Research, Development, and Test (3600) and Aircraft Procurement (3010) funding. While these efforts must be considered throughout the design and development of an aircraft, more than 70 percent of the funds required to develop, qualify, and operate an aircraft in service are spent in operation and maintenance. And the time spent in operation and support is much longer today than it ever has been in the history of the USAF.

Maintaining aircraft that are nearing the end of their design service lives requires an enterprise effort to maintain airworthiness, mission capability, and effectiveness for these aircraft. This is being done today, but only by extensive repair and remanufacture of the aircraft component by component. It also requires that upgrades be implemented to retain warfighting capability for fighters and bombers or fuel efficiency for transports and tankers.

Remanufacturing is expensive. One has to take the aircraft apart and reassemble it in order to accomplish the task and it cannot always be done without complete removal and reinstallation of systems in order to rebuild the structure around these systems. Thus, remanufacturing is very manpower intensive involving much "touch" labor and few opportunities for automation. The consequence of these actions is that costs for each Programmed Depot Maintenance cycle are increased markedly as the platform ages. Depot cycles are planned around parts obsolescence and usage – fatigue crack initiation and growth. But, aging (corrosion, sealant and wiring degradation, and exposure to ultraviolet light) adds additional failure modes and life limitations that reduce planned maintenance intervals or increase the work associated with maintaining these components. In addition, life extension requires continued airworthiness assessments and qualifications, involving structural life extension programs and many other expensive activities.

Because of these costs, the cost of operations and support for the fleet is going up rapidly even though the number of aircraft in the fleet is coming down as recapitalization falls. And with the reduction of recapitalization funding, the USAF fleet of tomorrow is very likely to look a lot like the fleet of today. USAF will simply be extending the lives of their aircraft as far as possible to maintain the fleet capabilities.

A sustainment enterprise has grown up to accomplish these tasks for the fleet of USAF aircraft. It includes maintenance organizations, acquisition organizations, parts and supply organizations, as well as funding and airworthiness organizations. The maintenance of the fleet is heavily MDS-centric, with each having their own maintenance plans and relationships between the organic sustainment organization and the original equipment manufacturer.

Challenges for the Sustainment Enterprise

Challenges for the sustainment enterprise include: lack of metrics for field maintenance and depot activities that measure efficiency; supply chains that are inefficient often due to the inability to accurately predict parts needs; increasing software maintenance requirements (both amount of code in systems and the complexity of the integration); the need for new technologies

ready for implementation at Air Force Materiel Command's (AFMC) Air Logistics Centers (ALCs); the difference between commercial maintenance practices and military; and the immaturity of some of the integrity programs.

The sustainment enterprise has metrics used to determine success in providing aircraft availability (for the ALCs and field maintainers) and Non-Mission Capable Rates (for the field maintenance operations) for the USAF. These metrics are reviewed regularly by Air Force leadership to guide decisions for future maintenance and upgrade activities. However, the targets for these metrics are set by the lead Major Commands (MAJCOMs) without regard for the funding required to meet the targets. Thus, the sustainment enterprise consistently falls short of the targets whenever funding falls short of the requirements, which is frequent. There needs to be a different metric for the sustainment community that allows them to know how efficiently they are performing rather than simply whether they are meeting prescribed targets.

In addition, the supply chain suffers from inefficiencies in meeting demand for parts and components and these deficiencies become more pronounced as the aircraft age and original parts suppliers go out of business. The problem becomes more pronounced as more commercial off the shelf (COTS) equipment is used because these parts become obsolete faster than military program lifecycles require.[2,3,4] COTS equipment used in Unmanned Air Vehicles suffers these same issues even though these systems are still in production. For example, while visiting General Atomics, the Study Panel was told that the Reaper (MQ-9) suffers one component obsolescence issue a week.[5] While current maintenance metrics address both hardware and software maintenance and upgrade activities, the software need is growing much more rapidly than hardware due to the integration of subsystems with software and the tie to the overall aircraft system by software. Aircraft functionality, from flight to mission to weapons, is all being linked by software both within components and through the system integration software. In fact, in some cases new functions are being added to existing hardware via software. Knowledgeable and capable software technology personnel will be increasingly required at ALCs to maintain this software as aging aircraft become more software dependent and the maintenance efforts become more organic due to 50/50 rules that require certain maintenance be done at the ALCs.

Commercial airlines maintenance procedures differ from those used in the USAF. They maintain aircraft at flight capable rates exceeding 90% (K. Davis, Senior Principal Engineer, Delta TechOps, Personal Communication, March 24, 2011) versus the 65-70% rates[6,7] seen for large transport aircraft in the USAF. They do as much repair and maintenance in the field as

---

2 Buxbaum, P. "Obsolescence Management."

3 Sandborn, P., & Singh, P. "Electronic Part Obsolescence Driven Product Redesign."

4 Lebron, R., Rossi, R., & Foor, W. "Risk Based COTS Systems Engineering Assessment Model."

5 SAA Study Panel visit to General Atomics Aeronautical Systems, Poway, CA, May 3, 2011.

6 Gregg, M. "C-5 Galaxy Division."

7 Tribble, G., et al. "Tactical Airlift Division."

possible and minimize depot maintenance, and they document the predicted depot maintenance so they know what parts are required before the aircraft ever hits the tarmac at the depot. This allows commercial airlines to run aircraft through the depot in 30-45 days (versus the USAF 180-280 days[6,7]) and schedule them so they are ready with the next induction as the prior is rolled out the door (K. Davis, Personal Communication, March 24, 2011). They have as few aircraft on the ground at the depot as possible because aircraft on the ground do not earn money. It is a different paradigm than the Air Force where every aircraft costs the USAF money whether it flies or not.

Finally, the integrity programs need to be strengthened, especially to bring the level of rigor in the more immature (MECSIP – Mechanical Systems Integrity, AVIP – Avionics Integrity, and CCSIP – Computer Systems and Software Integrity) up to those resident in the most mature (ASIP – Aircraft Structural Integrity and PSIP – Propulsion Systems Integrity). The MECSIP, AVIP, and CSSIP programs are just as valuable to airworthiness, fleet viability, and effectiveness of the aging USAF fleet as the ASIP and PSIP programs that have reduced aircraft failures due to structure and engines so markedly over the past half-century. But these other programs are far less mature and not yet providing the data, tools, and processes required to ensure the integrity of the USAF's aging fleet.

Technology Options

The Study has identified eight specific technologies that when applied to maintenance and repair could reduce inspection, rework, replacement and repair times, and costs in the depot. These technologies are identified herein:

- X-ray backscatter technologies that can detect cracks underneath fastened skins as well as determining submerged parts in complex components to ensure accurate remanufacturing
- Laser shearography technology that can be used to detect delaminations or corrosion in thin skin acreage structures
- Improved wiring diagnostics that would allow detection of crimps and breaks in complex wiring topologies
- Additive manufacturing: technologies that offer to produce larger and more complex replacement part geometries on demand directly from digital drawings
- Statistical (analytical) approaches for maintenance to modify industry models for military MDSs, and integrate maintenance, information technology, and research
- Improve point-of-maintenance data fidelity by validating and correcting inputs based on the inventory of the parts used, robust and miniaturized hand-held instruments for input
- More reliable, robust sensors that offer longer operation times, in-service feasibility tests, and component status indication
- Prognostics reasoners based on better data collection, predictive algorithms, and physics-based analyses

Overarching Findings

The Study finds that successful sustainment of the USAF fleet through the 21st century will require a revision in the processes and technologies used to efficiently maintain the fleet through at least mid century. The following six findings are the foundation for the recommendations that follow.

1. Sustainment investments are driven by aircraft availability set by the lead MAJCOMs, which may not correlate to resource utilization efficiency.
2. Diminishing Manufacturing Sources become an increasing sustainment issue as aircraft age and Original Equipment Manufacturer (OEM) involvement is reduced.
3. Software use/complexity and rapid technology refresh have grown faster than the USAF's ability to address it across the lifecycle.
4. Maintenance Science and Technology (S&T) is technically rich but not considered leading edge science by many in the research and development community.
5. Airline and Contractor Logistics Support organizations emphasize reliability data collection and analysis to schedule maintenance actions, optimize outsourcing of maintenance activities, and rely on independent airworthiness guidance from the Federal Aviation Administration.
6. The integrity programs contribute to managing and extending the life of aging platforms, providing data for FVB assessments, System Program Manager / Air Logistics Center upgrades, and maintenance scheduling, but not all integrity programs are providing the required data and processes.

Recommendations

The Study makes the following six recommendations to help reduce the cost burden for sustainment of the aging Air Force fleet through the mid 21st century. Each recommendation aligns with one of the overarching findings, and the Panel suggests an US Air Force office of primary responsibility (OPR) for implementing each.

1. Use existing USAF data to quantify and model the cost of aircraft availability (AA/$) as an efficiency metric and employ it, along with AA, to inform sustainment investment decisions for each MDS. [OPR: AFMC/A4]

   To implement this Recommendation, the Air Force should:

   - Quantify AA/$ as a function of Programmed Depot Maintenance rate over a broad range of costs to identify the "sweet spot" in efficiency.
   - Employ the model to analyze the efficacy of various sustainment initiatives being proposed to improve depot flow and efficiency.

2. Improve Air Force Global Logistics Support Center (AFGLSC) supply chain forecasting to minimize field level maintenance and depot production delays due to parts shortages. [OPR: AFMC/AFGLSC]

   To implement this Recommendation, the Air Force should:

- Implement an analytically based parts forecasting system utilizing part tracking, field history, and reliability data.
- Provide robust engineering support within the Program Offices and AFGLSC to permit technically sound sourcing decisions and Manufacturing Review Board activities.
- Develop supply chain metrics that tie to AA/$, not parts delivery.
- Promulgate the use of COTS obsolescence forecasting tools (e.g., the AVCOM tool) early in the maintenance planning cycle for all MDSs.

3. USAF should adopt an enterprise approach to software sustainment throughout the lifecycle of an MDS. [OPR: AFMC]

   To implement this Recommendation, the Air Force should:

   - Form enduring, time-phased collaborations with aircraft and aircraft system OEMs for predictable and cost effective software sustainment.
   - Mature CSSIP rapidly to establish disciplined processes and technologies to meet software qualification standards and software verification and validation (V&V) over the MDS lifecycle.

4. Increase AF Research Laboratory (AFRL) research efforts oriented to legacy aircraft maintenance needs and plan with the MAJCOMs for transition. [OPR: AFMC/A4, AFRL]

   To implement this Recommendation, the Air Force should:

   - Establish or increase fundamental research and development efforts in the areas of corrosion, stress corrosion cracking, accelerated aging testing, leak detection/prevention, wiring fault detection, and software research in V&V, self-describing code, readability, interoperability, etc.
   - Mature promising hardware maintenance technologies to Technology Readiness Level (TRL) 6 for technologies previously identified.
   - Create full-scale demonstrations for maturing TRL 6 and Manufacturing Readiness Level (MRL) 6 maintenance technologies to implementation (TRL 9 and MRL 9)

5. Institutionalize applicable commercial best practices. [OPR: AF/A4, AFMC/A4/PK]

   To implement this Recommendation, the Air Force should:

   - Adopt advanced technologies that improve quality and accuracy of maintenance data entry, searchability, and integration of databases to inform reliability analyses.
   - Expand Reliability Centered Maintenance practices to incorporate Maintenance Steering Group (MSG)-3 approaches, e.g., preventive maintenance throughout the field-level and depot-level sustainment enterprise.

- Improve contracting practices to explore use of incentive-based contracting mechanisms and utilize contract return on investment calculations longer than 5 years commensurate with expected platform life.

6. Make the entire suite of Air Force Integrity Programs an integral part of System Program Manager lifecycle management plans, FVB evaluations, and flight worthiness certification. [OPR: ASC/EN]

   To implement this Recommendation, the Air Force should:

   - Bring MECSIP, AVIP, and CSSIP Integrity Programs up to the high level of rigor resident in ASIP and PSIP.
   - Incorporate S&T advances in aging mechanisms and instrumentation into ASIP, PSIP, AVIP, and MECSIP: corrosion prediction methodologies, stress corrosion cracking, composite failure modes and strength prediction over time, and nondestructive inspection techniques.
   - Focus the AVIP process to provide the same elements as ASIP/PSIP, and implement into the associated Military Standards.
   - Mature CSSIP rapidly to establish disciplined processes to develop software qualification standards and provide guidance for verification and validation over the lifecycle of the platform.

Conclusion

The sustainment of aging aircraft like those in the USAF fleet is likely to become a more expensive activity in the next few decades. It will be important for the Air Force to become as efficient as possible in maintaining and upgrading these aircraft in order for them to remain viable members of the USAF fleet. There are many potential technological solutions that can help reduce the cost and time to perform these maintenance operations.

The Panel spent considerable time exploring means to achieve these efficiencies given the constraints imposed on the USAF sustainment enterprise. The Study made specific recommendations to:

- Examine aircraft availability per unit dollar to measure efficiency;
- Improve the databases used to determine parts and supply needs and to be able to search these databases;
- Improve the rigor and validation of software solutions for sustainment and upgrades of components and integration software;
- Explore specific technologies that might enhance the prediction capability for life of aging parts and subsystems;
- Emulate commercial airline practices in prediction of maintenance needs, outsourcing and contracting using longer term return on investment; and
- Bring the newer integrity programs up to the same level of rigor that is evident in the more mature ASIP and PSIP programs. Note: This will be especially needed for

CSSIP given the growth and dependence of USAF aircraft, both for newer platforms as well as legacy fleets, on software.

While these recommendations may not completely stem the cost growth for sustainment of the aging USAF fleet, they can certainly provide cost and time reductions from the systems currently used by the USAF sustainment enterprise.

Table of Contents

(This Page Intentionally Left Blank)

Table of Figures

(This Page Intentionally Left Blank)

Table of Tables

(This Page Intentionally Left Blank)

Section 1: Terms of Reference, Study Scope, and Approach

Air Force Scientific Advisory Board

Integrity - Service - Excellence

Sustaining Air Force Aging Aircraft into the 21st Century

Alan Eckbreth, Chair
Charles Saff, Vice Chair

The Air Force Scientific Advisory Board (SAB) is a Federal Advisory Committee. Therefore all statements, opinions, findings, recommendations, and conclusions contained herein are those of the SAB and do not represent the official position of the United States Air Force or the United States Department of Defense.

1

The Air Force (AF) Scientific Advisory Board (SAB) was tasked by Air Force leadership to perform a Study on "Sustainment of Air Force Aging Aircraft into the 21st Century." The Air Force has entered a time of reduced recapitalization for aircraft that will drive the Air Force toward retaining many of its aircraft beyond their original design service lives. This can be done but is an inherently expensive process that eventually remanufactures the aircraft entirely component by component as wear-out occurs. There are significant technical challenges to this sustainment effort which grow as failure modes become age driven rather than usage driven. This SAB Sustaining Aging Aircraft (SAA) Study has sought to identify key technologies that can reduce the time and expense for the Air Force sustainment enterprise in its quest to maintain and field these aircraft through the 21st century. The recommendations herein are based on findings reached from information discussed and reviewed in the explanatory briefing charts included in this report, and information resources listed in the corresponding appendices.

The traveling public has little idea how much effort is required to maintain aircraft in a flight-worthy condition. When events like the Aloha Airlines accident of 1988[8] occur (see Figure 1-1 below), the media sensationalize the event and distort the news. The public sees these events as unusual results of abuse of the aircraft or of a lack of care in maintenance. They hear about aging aircraft concerns, but they rarely encounter flight on aircraft that are truly aging. The Aloha aircraft had the second most flight cycles (take-offs and landings) of any 737 in the world at that time.

Figure 1-1. Aloha Airlines Flight 243 After Landing in 1988. Note the missing section of the fuselage crown and windowbelt.

The reality is that many aircraft in the US Air Force (USAF) fleet are two generations older than the aircraft involved in this incident. USAF aircraft are maintained by a staff of maintainers who do a remarkable job of not only maintaining these aircraft, but upgrading them to maintain their capabilities and their superiority to adversaries. They remanufacture those parts that are so old they are no longer available from the original manufacturer. In some cases, the aircraft are so old the original parts manufacturer may no longer exist.

In reviewing the results of this Study, the work of the men and women of the System Program Offices, the Air Logistics Centers, and the Contractor Logistics Support Centers must not be overlooked or underrated. Their efforts to repair, maintain, and upgrade USAF aircraft are the underpinnings of the fleet, both today and tomorrow. It is the intent of this report to give them greater knowledge, capabilities, and capacity and to enhance their efforts and increase their efficiency – the future of the USAF fleet depends on them. In an era of decreasing budgets and reduced recapitalization, the USAF fleet will be even more dependent on these people in the future. They need and deserve the best technology we can provide to enable them to perform to the best of their abilities.

---

8 National Transportation Safety Board. "Aircraft Accident Report: Aloha Airlines, Flight 243, Boeing 737-200, N73711, Near Maui, Hawaii, April 29, 1988 (NTSB/AAR-89/03)."

Outline

- Terms of Reference, Study Scope, and Approach
- Background
- Findings and Recommendations

The Terms of Reference, Study Scope, and Approach are all summarized below. This Study Panel did not address all the items in the Terms of Reference originally defined for it because the Panel found that other entities were better informed and better tasked to perform those studies and to a great degree were already doing so or had done so (e.g., the USAF Fleet Viability Board). Thus the Study Scope and Approach were refocused to provide answers to the key portions of the Terms of Reference for which the Study was tasked and to ensure the limited resources available to the Study Panel, in the considered judgment of the Study Panel members and the SAB Executive Committee, addressed the areas of highest potential payoff.

Note the three illustrations in the chart above. For each Outline chart (above and later in this report), photos exemplifying the work being done at Air Logistics Centers are included to show the level of effort being expended to maintain and upgrade these aging aircraft.

Sustaining Air Force Aging Aircraft into the 21st Century: Charter

- Identify specific aircraft systems, in addition to structures and engines, that contribute to safety, availability, and effectiveness for aging aircraft
- Using the FVB's prioritized list of aircraft, determine for all fleets the maintenance status of these aircraft systems, and rank them in terms of priority due to risk across Mission Design Series (MDS)
- Examine commercial practices in airlines, air freight services, and other industries, and evaluate how they can be applied to meet Air Force needs
- Assess the time and first-order investment required to complete needed mods of the high priority aircraft systems, and the resulting effect on operational availability of the fleets. Perform a first-order assessment of O&M cost savings and avoidance and military utility of improved capabilities that would result
- Recommend how the Air Force should proceed to address these modifications by MDS in priority due to mission risk, operational availability, and O&M cost
- Identify technology needs and technology approaches that can be applied or developed to extend life or ease maintenance of these aircraft systems, while facilitating future adaptations and performance enhancements of the aircraft

3

The Air Force will operate its legacy aircraft for decades beyond their originally projected service lives, stressing structures, engines, and other aircraft systems. The USAF Fleet Viability Board (FVB) was formed to assess the technical fitness and the associated availability and cost of continued ownership of Air Force weapon systems. While the Board projects the fitness of all fleet systems (e.g., structures, propulsion, avionics, offensive/defensive, and electro-mechanical subsystems), structures and propulsion are analyzed at the greatest depth. Addressing structures and engines is a complex task, but other aircraft systems can also be life limiting, pose flight safety risks, and affect aircraft availability, effectiveness, and Operations and Maintenance (O&M) costs. Investments in appropriate modifications/replacements are planned for some aircraft fleets, but deferred for others. For example, the FVB has identified service life issues associated with the landing gear of the A-10 Thunderbolt II, T-38 Talon, and F-15 Eagle fleets. Some of these fleets have scheduled depot maintenance for their landing gear or plans to replace existing landing gear with new hardware, but others are deferring these investments. There is a need to help the Air Force identify and prioritize investments in other aircraft systems while identifying how such investments can establish a foundation for future adaptations and performance enhancements.

The Terms of Reference (ToR) charter for the Study is shown in the chart above. There were several elements identified in the ToR that the Study did not consider in depth, as shown in gray. As part of the extensive series of visits made during the Study, to be detailed subsequently, briefings were received from the FVB and most legacy aircraft Mission Design Series (MDS) System Program Managers (SPM) or Chief Engineers, including deeper reviews of several systems most representative of aging aircraft in each MDS. The Study Panel determined that the

FVB and the SPMs know very well the fleets and their status as far as maintenance, configurations, and required upgrades to enhance mission capabilities. The FVB uses a team of up to 50 Subject Matter Experts to determine the status and project the viability of each MDS as it operates in the projected environment and usages provided by Major Command (MAJCOM) directives. This Study could not do in a few weeks what that team of experts does over a six month period. Thus, this Study did not review the maintenance status for each MDS or rank the maintenance priorities across MDSs.

In the same way, it was determined that there was very little value added in having this Study Panel review MDS modifications and try to determine the impact of those modifications on the operational availability of each MDS. While the Panel reviewed cost summary data and manpower expended for maintenance and sustainment of each MDS, the Panel members made no assessment of cost savings that might be afforded by each modification to an MDS. The System Program Managers have valuable data and experience that help drive good decisions for determining upgrades that will improve capabilities for each MDS.

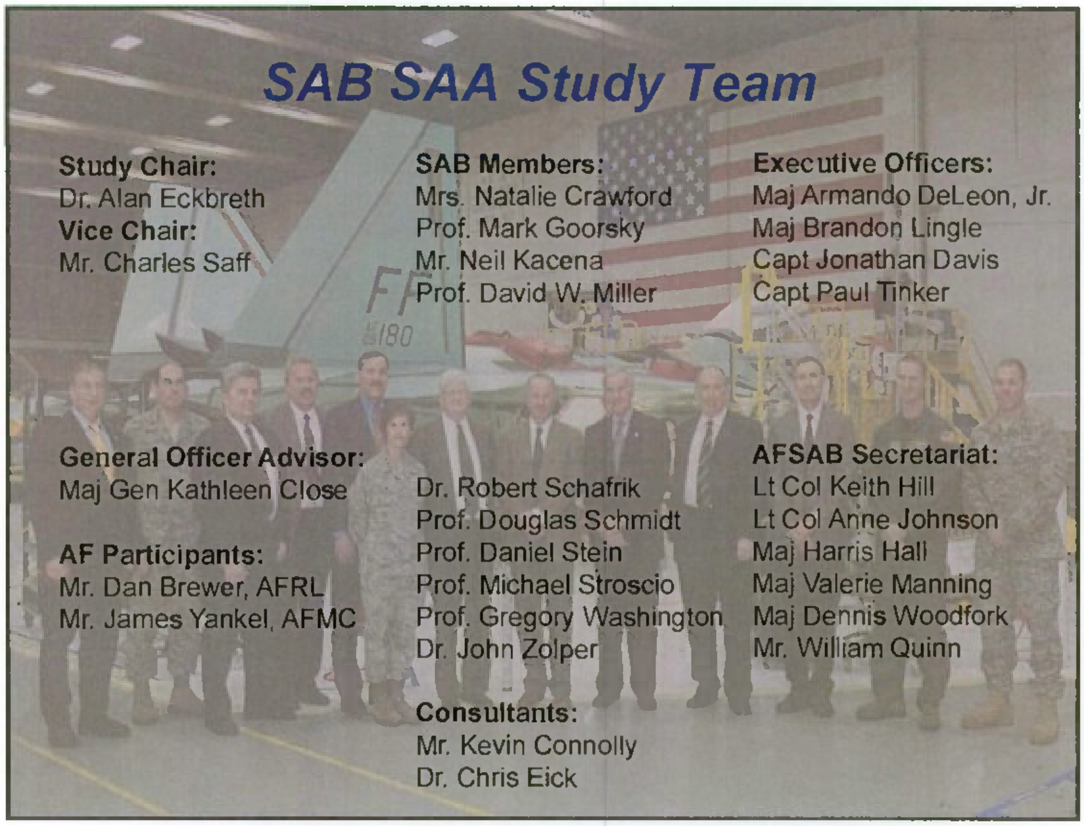
Likewise, this Study Panel did not identify or recommend ways that the Air Force could proceed to address high value modifications by MDS in priority due to mission risk, operational availability, and O&M cost. This too was felt by the Study Panel to be an area in which the FVB and the SPMs have much more data and experience with each MDS from which to determine which capabilities enhancements provide best value for each system.

In addition, the Study Panel did not look into Low Observables maintainability for reasons of focus and classification. Low Observables maintainability is a well-recognized maintenance challenge and is being addressed vigorously within the Air Force. Neglecting this subject area allowed the Study to remain at an unclassified level and permitted greater focus on aging issues.

The Study Panel concentrated on the charter elements in black as well as other general observations in reaching its Findings and concomitant Recommendations.

The Panel first focused on determining which subsystems, beyond structures and engines, contribute most to safety, availability, and effectiveness for aging aircraft. The needs of several design groups were determined based on review of the aging MDSs in that group. Based on these studies, a cross cutting series of maintenance technology needs was identified for each MDS and that list was integrated to determine a set of needs for a mission group and then for the USAF fleet as a whole.

For each of those needs, a list of cross-cutting maintenance technologies was identified and from that list, eight technologies were chosen that could most effectively reduce the cost and time required to maintain aircraft as the fleet continues to age. Focus was placed on maintenance of aging platforms rather than performance upgrades. Performance upgrades may happen as a result of maintaining aging aircraft in which parts obsolescence and a diminished supplier base reduce the number of original equipment spares available. But the focus of this Study was on technologies and actions that can reduce the cost of maintenance.



The membership of the SAB SAA Study Panel is listed above. In addition to SAB members and consultants, there was a General Officer participant from Headquarters Air Force Materiel Command (AFMC) and a representative from the Air Force Research Laboratory (AFRL). Additional information on Study Team members is presented in Appendix C. The Study Team was ably assisted by AF SAB Secretariat support and volunteer executive officers from Air Combat Command (ACC), AFMC, and Air Mobility Command (AMC). The Study Team is indebted to these individuals for their dedication and hard work in support of the SAA Study.

SAA Study Briefings, Visits, Input

Air Force / DoD
AF/A4/A5/A8/A9/CVR/A4L/A5R/A8X/A8P
SAF/AQX/FMC
AF FVB
NAVAIR (Industrial Ops)
NRL

MAJCOMs
ACC A4/A5/A8/ST, 1st FW, 388th FW
AETC A4M
AFMC A4
AFSOC CD/A4
AMC A4/A5/8/A9/ST
AFGSC A4/7

Other Gov't / FFRDCs
NASA (LaRC)
RAND

NRC Study
Lt Gen Mike Zettler, USAF (Ret)

AFMC
ASC/CC/EN/WI/WN/WW
AFGLSC/CC/EN/448 SCMW/635 SCOW
AFOSR
AFRL/RX/RZ/RB
Ogden ALC, Hill AFB
Oklahoma City ALC, Tinker AFB
Warner Robins ALC, Robins AFB

Contractor Logistics Support
Boeing
General Atomics
Lockheed Martin
Northrop Grumman

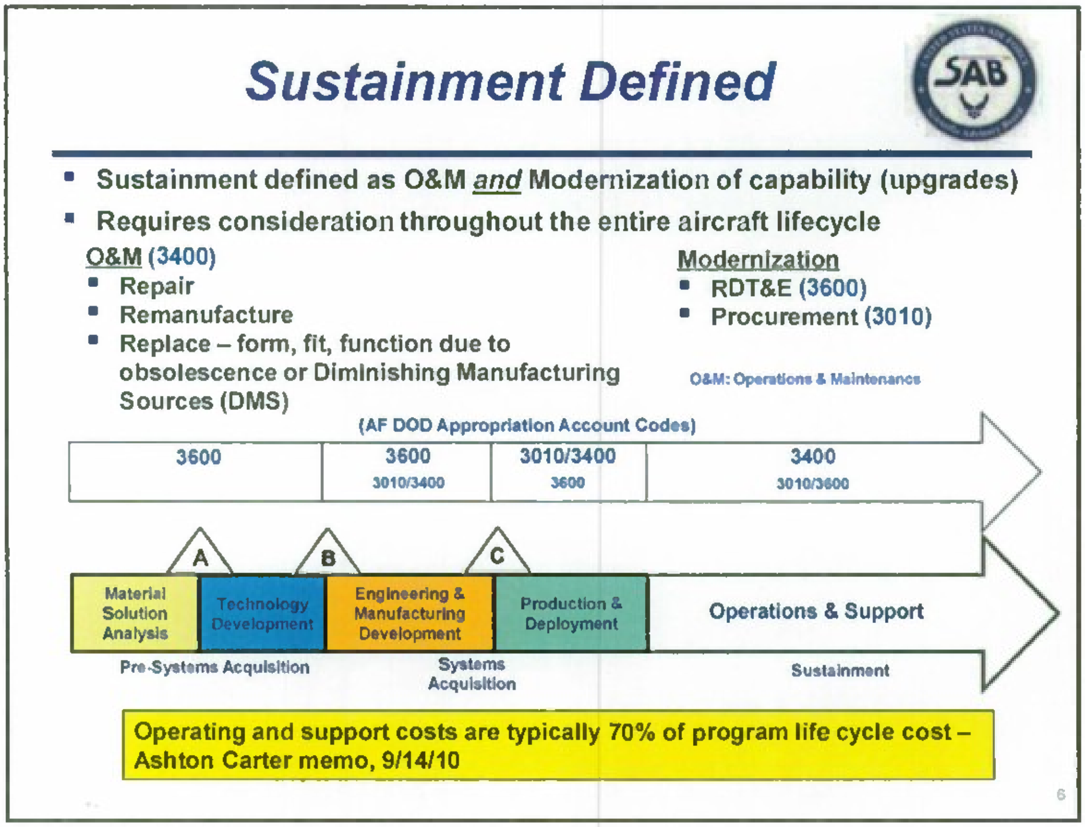
Commercial
Boeing Commercial Support
Delta Airlines Tech Ops
FAA
SMEs Ray Valeika, Clyde Kizer

ALC: Air Logistics Center

5

The SAA Study Panel received a large number of briefings, tours, and overview perspectives on aging aircraft and related issues in the course of the Study, from within and outside of the US Government. The Study members visited numerous USAF and other government facilities and personnel (e.g., Federal Aviation Administration and the Naval Air Development Center) to receive information. Locations included Wright-Patterson Air Force Base (AFB), Ohio; Hill AFB, Utah; Robins AFB, Georgia; Scott AFB, Illinois; and Tinker AFB, Oklahoma. The Panel also visited contractor facilities belonging to Boeing (Seattle, Washington, and Saint Louis, Missouri), Northrop Grumman (Palmdale, California), Lockheed-Martin (Marietta, Georgia), and General Atomics (San Diego, California). The Panel also was able to meet with Delta Airlines at their maintenance facility in Atlanta, Georgia.

A more detailed listing of the contributing organizations is included in Appendix D. The Panel is indebted to all of these organizations for the time and effort spent in preparing the many excellent briefings received and for the hospitality accorded the Study Team members by the hosting organizations.



For the purposes of this Study, sustainment is generally defined as both operations and maintenance and modernization of capability, i.e., upgrades. Modernization is also a part of O&M to replace in form, fit, and function obsolescent or unavailable parts. Although it is common to think of maintenance as those efforts in the field to maintain flying status, maintenance is used more broadly here to refer to all such activities, be they in the field, at back shops, or in the depots. Department of Defense (DoD) appropriation account codes govern which type of funding can be used to support these various activities.

During the life cycle of a weapon system, sustainment and subsequent funding requirements are identified. From the chart above, and depending on the stage of a systems life cycle, different appropriation accounts are used. For example, a majority of Research, Development, Test and Evaluation (RDT&E) (3600) funding is used through DoD Acquisition Milestones (MS) A and B. From MS B to MS C, 3600 remains the predominant funding appropriation, while some Operations and Maintenance (3400) and Procurement appropriations (3010) are used to initiate Operations and Support (O&S) and Procurement tasks as RDT&E activities decrease.

As the program moves through MS C, funding appropriations shift to 3010 as the predominant appropriation source.

In the Operations and Support phase, more commonly known as the sustainment phase, 3400 appropriation monies are expended as the weapon system matures and is fully employed in training and operational activities. The majority of 3400 monies in the sustainment phase are used for repair and remanufacture, and to modernize or overcome obsolescence issues. If, as the

weapon system ages and the lead MAJCOM identifies a modernization requirement (e.g., a new radar) then that modernization effort would be funded by both 3600 and 3010.

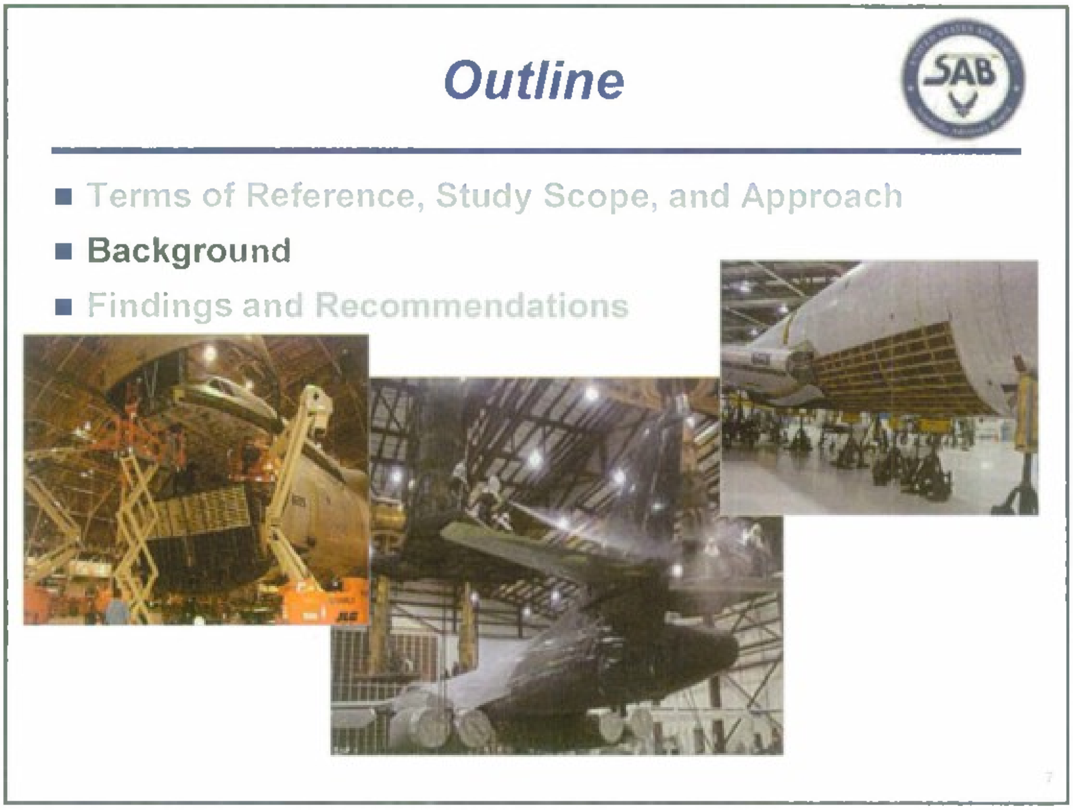
The canonical DoD lifecycle management chart typically shows sustainment as a box of equal size on the far right. However, the current reality of flying aging aircraft is that the sustainment phase is far longer (sometimes by at least an order of magnitude) than the first four phases shown. In addition, it accounts for nearly 70% of total system lifecycle cost. It is important that sustainment issues be considered throughout the life cycle but it is crucial in the design and acquisition phases.

Definitions – the following are key definitions used throughout this report:

- Sustainment includes maintenance and upgrades – it means keeping the MDS available and mission capable.
- Design Service Life means the equivalent flight hours to which an MDS has been certified by test and/or analysis.
- Equivalent flight hours are the actual flight hours multiplied by the severity factor for the loads/conditions encountered during the flight versus the loads/conditions for which the MDS was designed.
- Economic service life is the equivalent flight hour limit at which availability rates still meet needs with no more than planned service in the field or depot maintenance. Major overhauls, repairs, or replacements can restore or extend economic service life, but are beyond the scope of normal service.
- The economic life is the period during which it is more cost-effective to maintain and repair an aircraft than to replace it. Economic life can be applied on a component, aircraft, or force basis.
- Service life extension is more than structural refurbishment and certification testing. It should include system replacement and upgrades where feasible. Note: SLEP refers to Service Life Extension Programs (not Structural Life Extension Programs).

(This Page Intentionally Left Blank)

Section 2: Background



The Background section of the report presents information gathered from briefings to and visits by the Panel and is summarized below.

The declining trend for recapitalization (i.e., the procurement of new aircraft) of the USAF fleet leads to the necessity for the Air Force to retain its aging fleet longer than the initial design lives for these aircraft. This can be done, but only by extensive repair and remanufacture of the aircraft component by component. It also requires that upgrades be implemented to retain warfighting capability for fighters and bombers or for fuel efficiency improvements for transports and tankers.

Remanufacturing is expensive. In most cases, it is necessary to disassemble the aircraft, replace parts, then reassemble it in order to accomplish the task and it cannot always be done without complete removal and reinstallation of systems in order to rebuild the structure around these systems. The consequence of these actions is that costs for each Programmed Depot Maintenance (PDM) cycle are increased markedly as the platform ages. Depot cycles are planned around parts obsolescence and usage based on structural fatigue crack initiation and growth. But, aging adds additional failure modes (via corrosion, as well as insulation and sealant degradation, etc.) and life limitations that reduce planned maintenance intervals or increase the work associated with each of them.

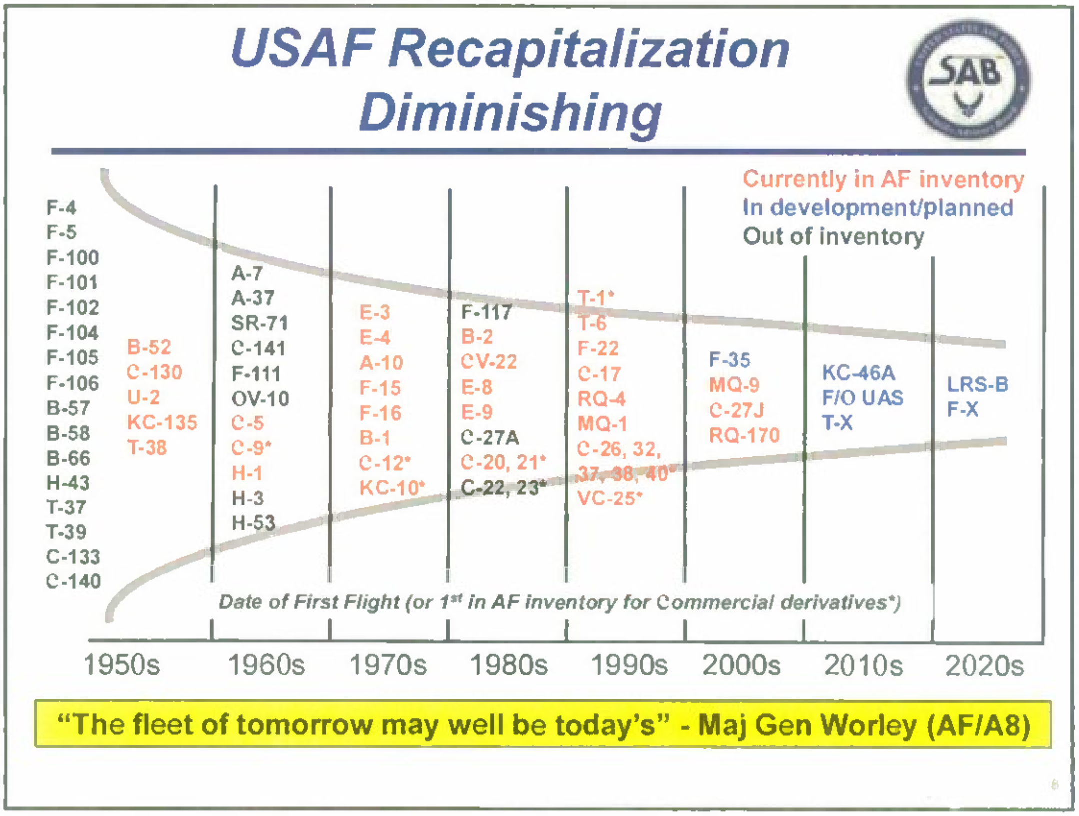
A sustainment organization has grown up to accomplish these tasks for the USAF fleet. It includes the maintenance organizations, the program management organizations, as well as funding and airworthiness organizations. These organizations have metrics they use to determine their success in providing aircraft availability for the USAF. These metrics are reviewed regularly by the Air Force Chief of Staff and help guide decisions for future maintenance and upgrade activities. These metrics include both hardware and software maintenance and upgrade activities. But software is growing much more rapidly than hardware due to the integration of subsystems with software and the tie to the overall aircraft systems functionality by software.

In addition, the supply chain suffers from inefficiencies in meeting demand for parts and components and these deficiencies become more pronounced as the aircraft age and original parts suppliers are no longer in business or stop manufacturing legacy parts. In addition, commercial parts become obsolete faster than military program lifecycles require. Commercial-off-the-Shelf (COTS) equipment used in unmanned air vehicles suffers these same issues even though these systems are still in production. For example, during its discussions at the General Atomics facility, the Panel was told that the Reaper (MQ-9) suffers one component obsolescence issue a week.

Commercial airlines maintain aircraft much differently than the USAF. They maintain aircraft at flight capable rates exceeding 90%, they do as much repair and maintenance in the field as possible and attempt to minimize depot maintenance, and they well document the depot maintenance required so they know what parts are required before the aircraft ever hits the tarmac at the depot. This requires highly skilled, trained, and resourced service technicians in this field, but it allows commercial airlines to run aircraft through the depot in 30-45 days and schedule them so they are ready with the next induction as the serviced aircraft is rolled out the door. They have as few aircraft on the ground at the depot as possible because aircraft on the ground do not earn money. It is a different paradigm than the Air Force where every aircraft costs the USAF money, whether it flies or not.

One of the key lessons learned from the commercial airlines is that they rely on Reliability Based Maintenance and preventive repair and replacement more than USAF does. The USAF has been focused on Condition Based Maintenance in which there is some indication of the pending failure of the component rather than just statistical analysis of previous failures. It saves the Air Force money by reducing the number of replacements they do, but it imposes more risk on flights and it imposes more down time on the depot work when parts are not ordered until they fail. Commercial airlines do fly to fail those components that are not critical to flight safety and they stock those parts according to their historical averages for part replacement. But military aircraft have fewer non-mission capable functions than airliners.

There are science and technology developments in work at AFRL and industry that could help maintain and sustain the USAF fleet. There may need to be a rebalance between the research and development investments made by AFRL in order to mature these technologies and bring them to the levels required by the Air Logistics Centers (ALCs) in order to implement them in their facilities. Full scale demonstration of the technologies will be required to interest the ALCs for they have no means to purchase and mature technologies that are not ready for turn-key operation.



The above chart is a snapshot of the inventory of aircraft in the USAF fleet arranged by the date of first flight (adapted from Arledge[8]). Although not part of this chart, both current and potential adversaries continue to develop and improve their capabilities, many facilitated by the commercial development and global access to militarily applicable technologies. These emerging threats require all front line fighters and bombers to be continually upgraded in capabilities either via hardware or software.

Most notable on this chart are the number of aircraft types no longer flown, and the number of aircraft currently flying that were first flown between 1950 and 1980. Some aircraft first flown several decades ago are still in production (e.g., C-130) and the newer models reflect modern day standards. Many of these aircraft are at least 30 years old and, in many cases, are projected to retire beyond 2040. Even if they are maintained well and see no greater usage than originally planned, many are older than any US airline aircraft flying in commercial service (commercial aircraft experience a much higher usage rate, but a more benign severity than most of these USAF aircraft ever see). Even the USAF's newer aircraft are projected to be in service very long times. For example, the B-2 is currently projected to retire in 2058 (see Table 2-1 on Aircraft Average Age below[9]).

---

[9] Arledge, E. "AF/A4L Perspective on Sustainment of Aging Aircraft."

An important conclusion to be drawn from the chart above is that the number of aircraft being planned for recapitalization is far fewer than those in today's inventory. DoD's current (Congressionally mandated) 30-year fixed-wing aircraft investment plan[10] indicates the following:

- There will be a hiatus of at least 10 years in production of new strategic airlifters and long-range bombers.
- The C-17 airlifter is likely to undergo significant service life extension programs (SLEP) beginning late this decade.
- The KC-46A is the only new airplane procurement though 2025.
- The USAF will buy less than a dozen tactical transports per year on average (i.e., C-130J and C-27J).
- As currently planned but likely to change, the projected F-35 buys build slowly and level off, not meeting required force levels until 2035 at best.
- Air Combat Command (ACC) is currently defining the general capabilities of a projected F-22 replacement; however, it will probably not be available until about 2030.
- Replacement of E-3 Airborne Warning and Control System, RC-135 Rivet Joint, and E-8 Joint Surveillance and Target Attack Radar System will be in the "far term;" however it is possible that advances in Unmanned Aerial Systems will affect replacement strategy for those systems.

---

[10] United States Department of Defense. "Aircraft Procurement Plan Fiscal Years (FY) 2012-2041."

Aircraft Type	DSL (hrs)	CSL (EFH)	RSL (EFH)	Number of Aircraft	Average Age Now	Projected Retirement	Age at Retirement
A-10	6,000	See Note	16,000 EFH	347	29.3	2040	59.3
B-1	9,681	14,522	NA	66	23.1	2040	52.1
B-2	10,000	20,000 AFH	NA	20	16.2	2058	64.2
B-52	5,000	27,700 AFH	NA	76	48.8	2040	~79
C/KC-135 R/T	NA	39,000 AFH	NA	417	49.1	2045	84 years
C-130E	NA	38,000 EFH	NA	46	47	2012	49
C-130H	NA	38/60,000 EFH (based on Wing)	NA	268	24	*	*
C-130J	NA	38/60,000 EFH (based on Wing)	NA	68	4.7	*	*
C-5A/C	30,000	47,200 EFH	NA	59	38.9	2011 - 17 2012 - 5 2040 - 37	39.5 40.5 68.5
C-5B/M	30,000	52,500 EFH	NA	44/6	22.7/26.1	2040	54
C-17	30,000	45,000 EFH A/C Structure	NA	206	8.1	2028	26.1
E-3	30,000	30,000 EFH	NA	23/9	32.1/27.5	**	**
F-15 A/C/D	4,000	9,000 EFH	14,250 EFH	250	26.8	2025**	41.8
F-15E	8,000	8,000 EFH	16,000 EFH	222	18.8	2035**	43.8
F-16 C/D	block dependent	block dependent	block dependant	1023	20	2026	36.3
F-16 Blk 30/32	8,000 (Goal)	10,800 EFH	10,800 EFH	317	22.5	2014-2025/2025	38/43
F-16 Blk 40/42	8,000 (Rqmnt)	8,000 EFH	8,000 EFH	395	19.9	2016-2025/2020	35/40
F-16 Blk 50/52	8,000 (Rqmnt)	8,000 EFH	8,000 EFH	245	15.6	2020-2030/2026	36/37
F-22	8,000 (Rqmnt)	8,000 EFH	8,000 EFH	166	3.6	2033-2049	27-34
KC-10	60,000	60,000 EFH		59	25.7	2042	57.7
EC-130H	NA	38,000 EFH	NA	14	37.3	2035	62
AC-130H	NA	38/60,000 EFH (based on Wing)	NA	8	41.0	2018	48
T-38	7,000	See Note	NA	494	43.5	2026	~60

Table 2-1. Average Aircraft Age Now (2011) and Projected at Retirement.

Thus, it seems nearly-certain that the aircraft flying now in service will need to fly for decades longer if USAF force structure is to be maintained at anything like its current size. This leads to Major General Worley's words[11] to the Study Panel that "the fleet of tomorrow may very well be today's." Moreover, the time to develop new aircraft today is very long (see Figure 2-1 below) and delays in development of current aircraft, like the F-35, ensure that the USAF's legacy fleet of F-16s will be required to fly for a decade longer than planned, requiring

[11] Major General Robert M. Worley, USAF, during presentation to AF SAB SAA Study Panel January 13, 2011.

modifications and upgrades in order not only to fly, but to be viable against adversaries who are fielding advanced weapon systems. Today's fleet is much more dependent on well-resourced, robust, and timely sustainment efforts rather than new systems procurement to provide the capabilities needed for the warfighter.

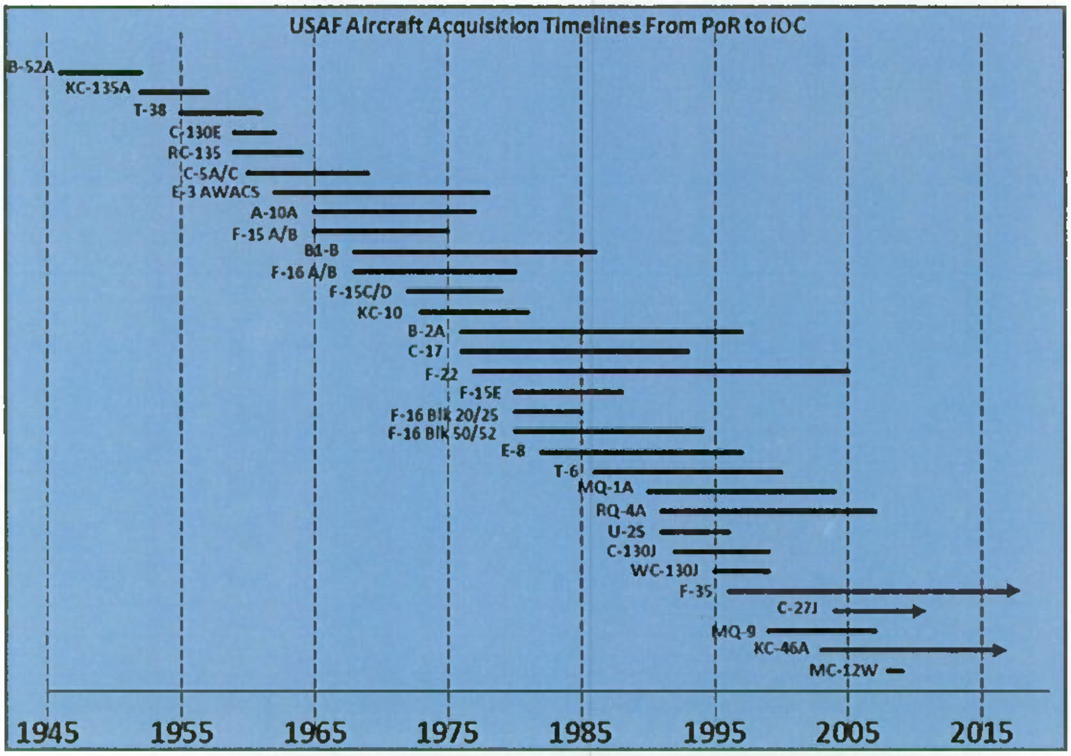


Figure 2-1. Timelines to Recapitalize. Note the generally increased timelines from Program of Record (PoR) to Initial Operational Capability dates from the 1950s to the 2000s).

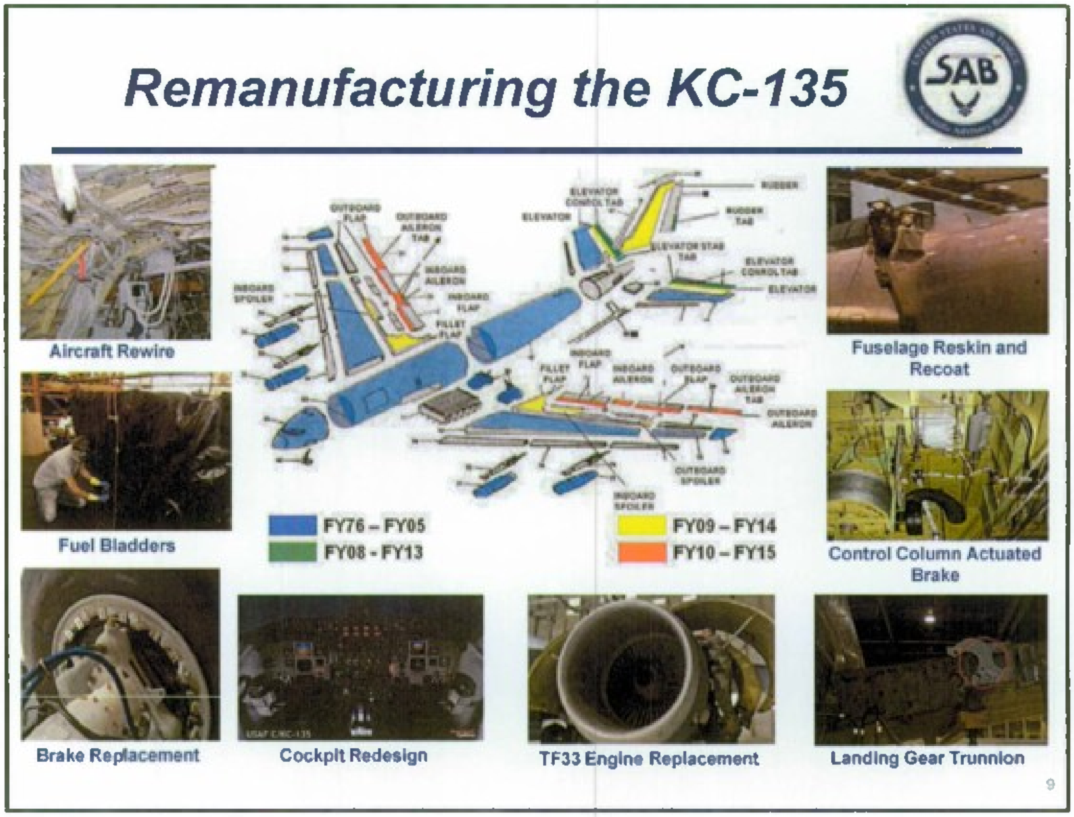
Adversaries continue to develop new and advanced capabilities, exacerbated by the fact that key military technologies are widely accessible on the global market because the US military-industrial complex is no longer dominant in the development of technologies for military use. Many of these technologies are driven by Moore's Law accelerating the pace of improvement and the requirement for modernization of United States forces. Recapitalization has been significantly delayed and, therefore, the existing USAF force structure continues to age, in many cases well beyond its original design life. The result is ever increasing sustainment costs that include both maintenance (maintaining the existing fleet) and modernization (adding and improving the capabilities of the existing fleet against an improving set of threats). It is this challenging environment that sets the stage for the SAA Study.

The initial Study premises, which follow, and observations further define and constrain the environment described above.

- Aircraft can be sustained almost indefinitely by remanufacturing, but it is very expensive

- Sustainment is driven by today's needs, but, in a constrained resource environment, it will be at the expense/delay of next generation aircraft.
- Technological superiority declines over time.
- 4^{th} generation fighters cannot be modernized into 5^{th} generation fighters.
- Early generation "heavies" can be advanced with re-engining, avionics upgrades, and other modernization programs.
- USAF recapitalization is driven more by need for enhanced capability than by age or rigorous economic service life (ESL) models.
- Recapitalization has become a long and oft-contested process and generally requires investment streams over several Future Years Defense Programs (FYDPs).
- Modernization of legacy capability can generally be accomplished within a FYDP. Maintenance triages today's needs.
- If the Air Force does not buy new, it must still sustain capability.

Simply stated, as the Air Force recapitalization process continues to be stretched out, sustainment of existing aircraft is increasingly expensive and the mission demands are not standing still. Both peer and non-peer threats continue to develop and challenge United States interests, driving the need for USAF capability improvements and sustainment. The FYDP funding process exacerbates the situation, favoring the ease of supporting shorter period of performance (inside one FYDP) associated with legacy modernization as opposed to the consistent longer term investment support required by recapitalization.



Aircraft can be sustained almost indefinitely by remanufacturing. A case in point is the KC-135 aerial tanker aircraft. Since its inaugural flight in August 1956, the KC-135 has been utilized extensively to refuel Air Force, Marine, and Navy tactical fighters and bombers. It is one of six military fixed-wing aircraft with over 50 years of continuous service and the fleet is forecasted to operate until at least 2045 (see Table 2-1, previous). In order to sustain the current high level of operational tempo (greater than 500 hours per aircraft per year), the KC-135 has gone through a substantial amount of modernization and component replacement, in addition to repairs associated with programmed depot maintenance. A display[12] of some of the major modifications and the dates (past, present, and future) are shown in the above chart and also provided below:

- Lower wing skins and fuselage replacement – 1976 thru 1988
- Aircraft rewire – 1985 through 2015 (six phases)
- Multi-point refueling system upgrade (upgraded 20 aircraft) – 1995 thru 1998
- Pacer - Compass Radar and Global Positioning System (GPS) (Pacer-CRAG cockpit upgrade) – 1996 thru 2002

---

[12] Gann, G. "KC-135 SAB Modifications."

- Global Air Traffic Management avionics upgrade – 2002 thru 2011
- Fuel bladder upgrade – 2007 thru 2013
- Flight controls upgrade – 2008 thru 2015
- Block 45 avionics upgrade – 2012 thru 2021

This process of making significant upgrades to aircraft to maintain availability and reliability while improving capability has been an integral part of AF practice and extends to multiple MDSs. This process includes bombers, trainers, and tankers but has limited application to fighter aircraft as 4th generation fighters cannot be modernized into 5th generation fighters (radar cross section, internal weapons carriage, sensors, data fusion, and connectivity separate 4th and 5th generation aircraft).

Another case is the T-38. The Northrop T-38 Talon is a twin-engine supersonic jet trainer. Since its inaugural flight in March 1959, the T-38 has been utilized extensively by the US Air Force, US Navy, and NASA as a trainer. The T-38 is forecast to operate until at least 2026. In order to sustain a high level of operational tempo, the T-38 has also gone through a substantial amount of modernization and component replacement although not as extensive as the KC-135. The major remanufacturing thrusts have been focused in four areas (A. Myers, Oklahoma City Air Logistics Center Aerospace Sustainment Directorate, Personal Communication, June 14, 2011):

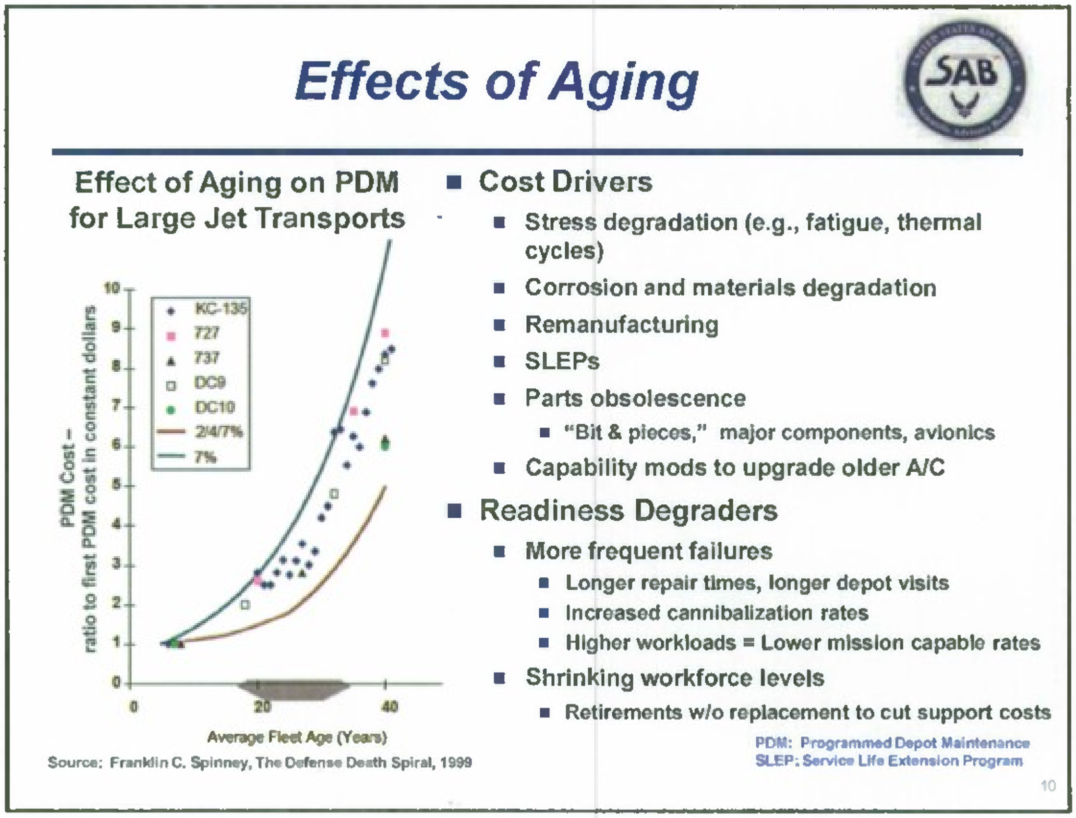
1. Structural: These included the Pacer Classic I-III programs that focused on cockpit, dorsal, and nacelle longerons and fuselage skin.
2. Avionics: The avionics upgrade program was initiated to reduce the technology gap between training and operational aircraft (Fiscal Year (FY) 11-13).
3. Safety: These efforts have focused on upgrading the landing gear, escape system upgrade (replaced legacy ejection seat), and anti-skid braking systems (FY09-11).
4. Propulsion: Replaced legacy T-38 engines with updated versions.

While this framework has been successful across multiple MDSs, there are a number of drawbacks. The first is the cost of remanufacture, which can exceed the cost to manufacture a new aircraft when total life cycle costs are included. The second is that remanufacturing almost always comes at the expense or delay of the development of next generation aircraft. This practice will assure that technological superiority will at best remain constant and could possibly decline over time.

As an example, the C-130 inner wing box replacement takes 300 people 180 days to perform.[13] Regardless of the cost of the fabrication of that inner wing box, it would be interesting to examine a trade between the cost of this rewinging exercise and the price of a new C-130 coming off an existing production line.

---

[13] Rector, G. "C-130 Repair, Upgrades Adding to Robins Workload, Credibility."



As the Air Force relies on sustaining and modernizing aging aircraft to constitute the bulk of its fleet, it must confront the issue of how aging drives costs. There are two distinct types of aging: chronological aging and cyclic aging or usage. Chronological aging is driven by multiple temporal factors, such as: system obsolescence, problems related to corrosion and environmental degradation at the basing location, and wear. Cyclic aging is driven by the way in which the aircraft is operated or used, such as: fatigue cycles, thermal and stress damage. Both of these aging modes impact the rising O&M costs as the aircraft age.

Besides costs, aging also results in lower aircraft availability (AA), as will be discussed subsequently. More frequent breakdowns, longer repair times, higher workloads, and a shrinking workforce all result in decreasing AA. The chart above shows the nearly 7% annual escalation in Programmed Depot Maintenance with average fleet age for a variety of large transport airframes including the KC-135.

The issue of how aging affects cost and readiness is of central concern to the Air Force, and an understanding of aging effects is therefore imperative as the Air Force relies increasingly on older systems. Several studies addressing the question of how aging affects costs have arrived at different conclusions. An early and influential RAND study was chaired by Raymond Pyles.[14,15] Reviewing historical PDM cost growth and analyses of engine life-cycle costs for the

---

[14] Pyles, R. "Aging Aircraft: USAF Workload and Material Consumption Lifecycle Patterns."

KC-135, 727, 737, DC-9, and DC-10 (the systems shown in the chart above), the Pyles study found a five- to nine-fold increase in heavy-maintenance workloads over a 40-year span. Earlier studies[16] had indicated annual age-driven growth rates of 4.5% and 5.3% for depot and base-level engine repair, respectively. (However, these studies did not include modular engines for fighters.)

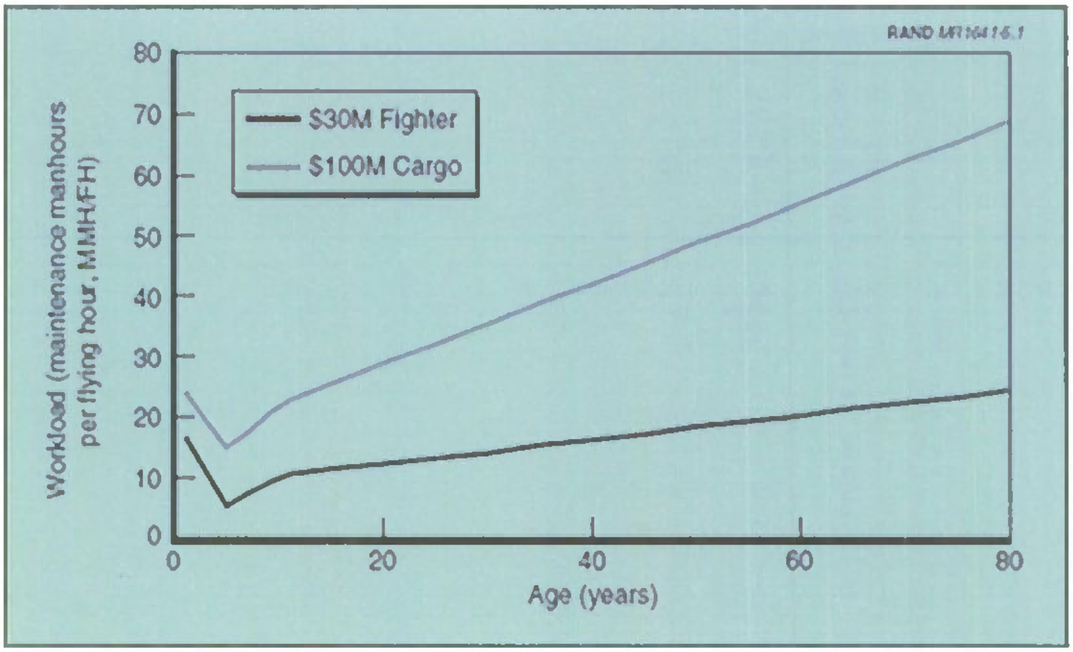


Figure 2-2. Maintenance Man Hours/Flight Hour as Aircraft Age for Two Levels of Aircraft Cost. (Source: Pyle).

The Pyles study showed that while the increase in PDM manhours varied with MDS, the general trend was increasing PDM work tasks (i.e., manhours and bill of materials) with age, with notable increases being evident after 20 years of life. The variation with MDS is most notable between smaller fighter aircraft which grow more slowly than the larger transport aircraft (see Figure 2-2). The potential for fighter cost growth tends to be driven more by usage while transports are generally driven by age. It is also possible that upgrades for combat capabilities may reduce the influence of age on fighter aircraft. This SAA Study also saw examples where the PDM manhours increase with the age of the aircraft but are MDS specific.

Using these results, the Pyles group extrapolated estimates of PDM workloads over a 70-year period. Combining these predictions with the engine-support workload, 1994 PDM

---

15 Pyles, R. Congressional Testimony: "Aging Aircraft: Implications for Programmed Depot Maintenance and Engine Support Costs."

16 Nelson, J. "Life-Cycle Analysis of Aircraft Turbine Engines."

expenditures, and the USAF's time-phased aircraft fleet composition plans, they estimated annual PDM and engine-support costs through the year 2022. Their results indicated that, after an initial modest rise in annual costs over the first decade of the 21st century, there would follow a sharp increase primarily driven by increasing age of the cargo and tanker fleets.

Recognizing that no one had operated aircraft over such a long period, the Pyles group also looked into factors that could either mitigate or exacerbate the growth in annual costs. They identified three broad strategies to reduce uncertainties and mitigate the effects of surprises: selective risk management, development of contingency plans for aging fleets, and mission-area portfolio management.

Another report[17] conducted through Headquarters USAF came to a different conclusion. Based on a purely statistical analysis, this report concluded that Operation & Maintenance Cost per Flying Hour (O&M CPFH) is strongly correlated with calendar year, but not with aircraft age. Using the KC-135 as an historical example, and adjusting for inflation, the authors found a roughly 2% growth in O&M CPFH from 1977 to 2002 (although with a good deal of fluctuation along the way). However, if one also adjusts for changes in financial accounting practices (the exact practices were not specified in the briefing), they found instead a 1% decrease. If one restricts oneself to a 10-year window from 1992-2002, one finds instead a rough 7% increase in both cases (the agreement presumably indicating that implementation of accounting changes preceded this period).

An earlier analysis by the group using a "two-component" model (one component being aircraft-specific and the other fleet wide) found that most of the fluctuations in cost seemed to be driven by calendar year rather than aircraft age. To support this conclusion, the authors analyzed the data using a Principal Component Analysis (PCA). This is a "variable-directed" technique, meaning that it's useful for studying the relationships among different variables that can influence an outcome. PCA is especially appropriate when one has a large number of variables that seem to be on a more or less equal footing, as opposed to, say, a case where one has a dependent variable and several explanatory variables, in which case one normally does a multiple regression analysis.

Using a PCA analysis, Larkin[18] found that the main driver of CPFH could be attributed to crude oil prices and real wages, and therefore correlated with calendar year and not aircraft age. However, a significant component of fluctuations remained unaccounted for. The main conclusion is perhaps not surprising, but including fuel costs can mask the effects of aircraft age. There are also issues about what goes into the CPFH even when subtracting fuel costs. Another factor that could influence the outcome but that didn't appear to be considered is an "order effect," O&M costs can depend on whether an aircraft was one of the earlier ones to be produced or came along much later. This effect could contribute to the calendar year component, while in fact the cause is quite different.

---

[17] Larkin, M., & Hannan, S. "Common Component Cost of Aircraft O&M Cost: Principal Component Analysis Approach."

[18] Ibid.

In a third study,[19] Gebman identified factors contributing to increasing O&M costs. The factors identified included: funding environments that lead to a reactive-mode approach to sustaining aircraft, the increasing difficulty of obtaining replacement parts as the already old fleet ages further, as well as a large number of physical phenomena such as rising corrosion-related costs, and generalized fatigue damage.

The Panel has received briefings at various bases supporting the notion that aircraft age is an important component in determining costs. The experience of the ALCs confirms this. A number of ongoing problems are age-specific. For example, wiring presents continual problems due to accumulated damage from long-term exposure to chemical, thermal, electrical, and mechanical stresses. Corrosion continues to be a serious issue that drives costs higher. These and other problems are purely a function of aircraft age.

One factor that can contribute to masking the effects of aircraft age is restricted O&M funding, which can preclude addressing problems that are specific to aircraft age. However, it seems very likely that chronological age does drive up costs for certain platforms at least.

Not all MDSs show a correlation with age. Those that do most clearly are the cargo transports and bombers, due to the lower severity usage per year/age so that usage is not a major factor. The graph shown in Figure 2-3 (below) shows the effect of aging on depot maintenance for the C-5.

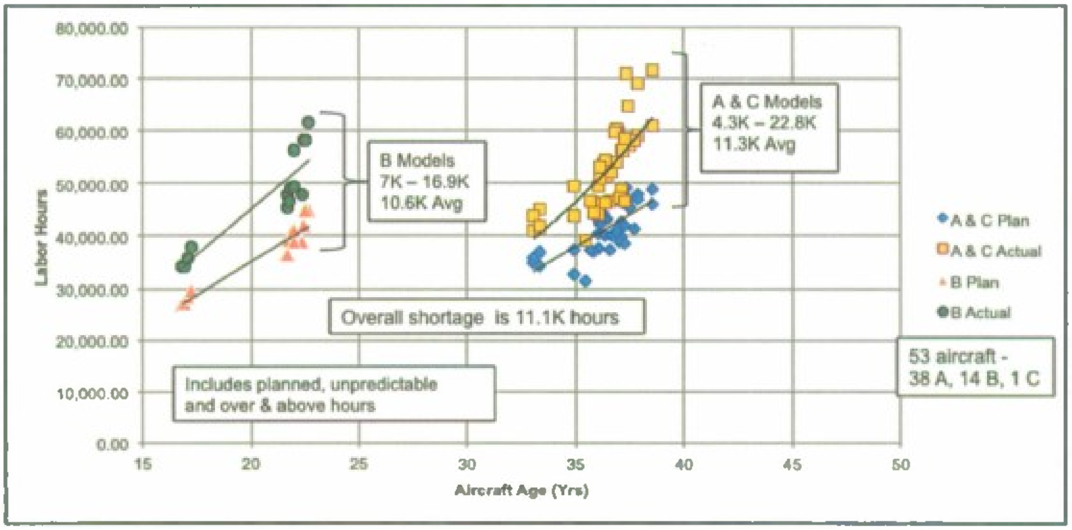


Figure 2-3. Effect of Age on Maintenance Costs for C-5 Aircraft.[16]

At briefings given at Warner-Robins ALC (WR-ALC), the effects of age on maintenance costs for both the C-5 and C-130 were presented.[20,21] The C-5 has one of the highest operating

---

[19] Gebman, J. "Challenges and Issues with the Further Aging of USAF Aircraft: Policy Options for Effective Life Cycle management of Resources."

[20] Gregg, M. "C-5 Galaxy Division."

costs of any platform, and the trend is towards a steady rise in reliability and maintenance costs. Data presented at the briefing (shown in the above chart showing C-5 PDM maintenance manhours versus aircraft age) plots projected and actual O&M labor hours expended for each of the different C-5 models. Although the newer and structurally improved B-series C-5 requires fewer maintenance man-hours per flying-hour than the older A-series aircraft, three important conclusions applying to all series can be drawn from these data. First, in all cases the actual maintenance man-hours significantly exceeded planned or projected maintenance man-hours. Second, the data show a strong and direct correlation between aircraft age and maintenance man-hours per flying hours, regardless of whether one looks at the older or newer series. Finally, and perhaps most worrisome, the rate of increase of maintenance manhours (i.e., the slope of the line plotting labor hours vs. aircraft age) is higher for the actual data compared to the projected costs. This again holds across the board for all models.

Another briefing at WR-ALC concerned the C-130 platform. Data presented[22] are shown below in Figure 2-4.

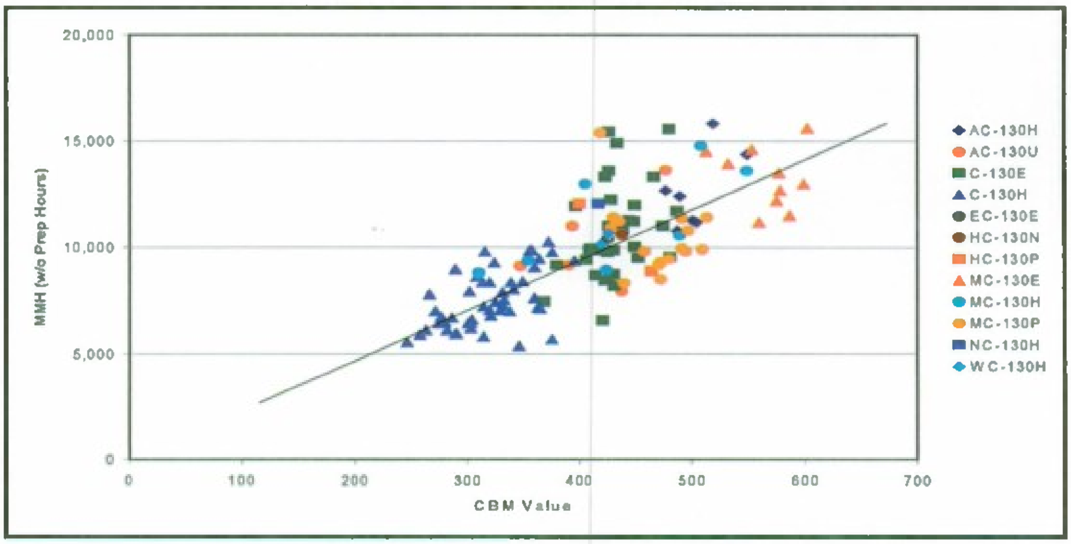


Figure 2-4. C-130 Maintenance Manhours (MMH) vs Condition-Based Maintenance Values.

A linear regression analysis on data comprising 133 aircraft, representing 12 different models, (see Figure 2-4 above) shows a strong linear dependence of corrective maintenance man hours (MMH) on a condition-based maintenance (CBM) value. The latter folds in a variety of factors, but three-quarters of its value is derived from aircraft age and corrosion, with the remainder driven by flight severity; as a consequence, the correlation of MMH with age is

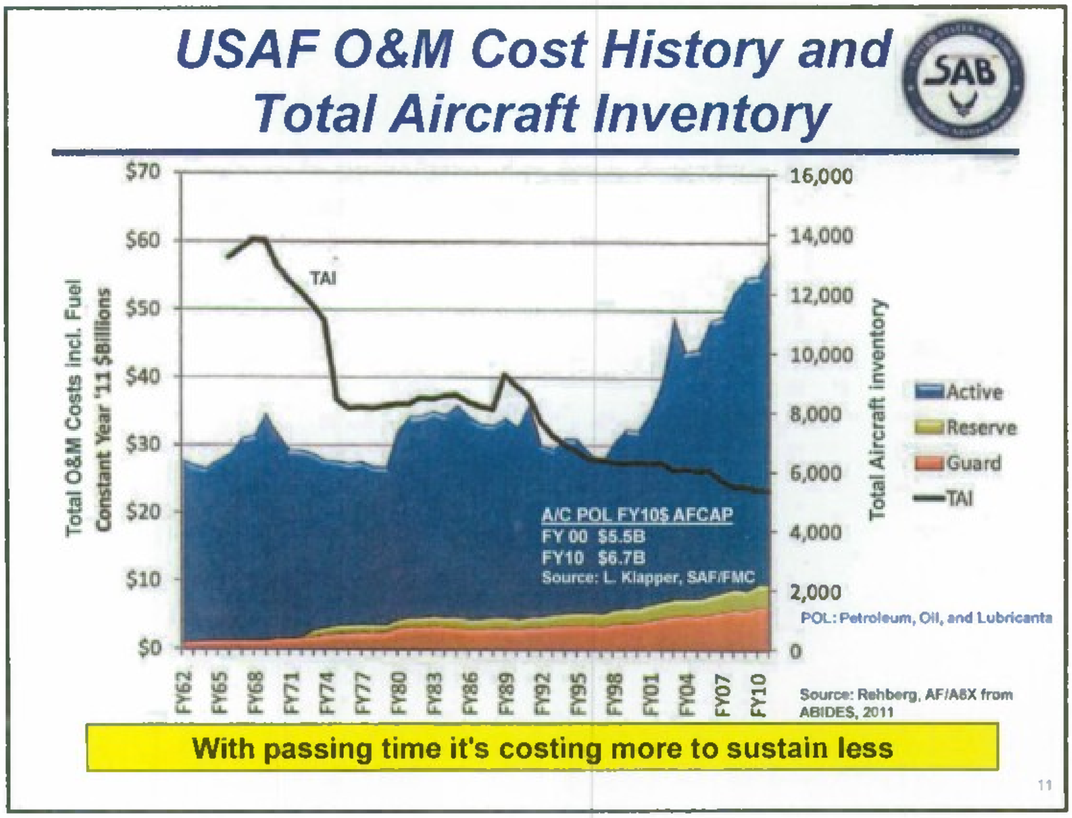
---

[21] Tribble, G., et al. "Tactical Airlift Division AF Scientific Advisory Board."

[22] Ibid.

strong. Eighty percent of the aircraft shown in the chart are within 20% of the predicted value, a good indicator of a strong correlation. (More precisely, the coefficient of determination (R^2) parameter equals 0.57, indicating a good fit.) The inescapable conclusion is that for the C-130 platform, O&M costs directly correlate with aircraft age.

This Study concludes that age plays a significant role in increasing O&M costs but it is not the only factor.



The above chart shows financial data, in FY11 dollars, from the USAF's Automated Budget Interactive Data Environment System from 1962 to 2010 for the operation and maintenance (O&M, AF appropriation account code 3400) cost of the total aircraft fleet in inventory (TAI). While TAI has decreased dramatically over this period, the O&M costs have escalated.[23]

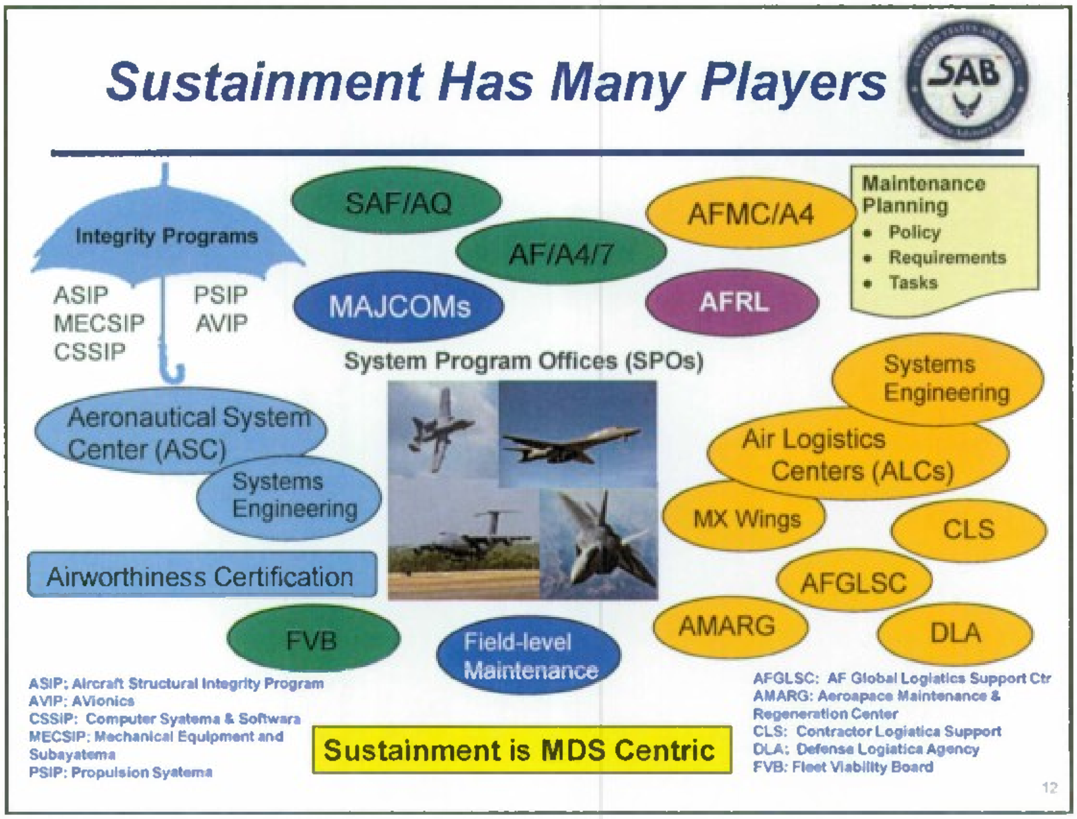
The decrease in TAI from 1968 to 1974 is associated with the USAF's draw down following the Vietnam War. The peak from 1989 to 1991 is associated with the Reagan Administration build-up, followed by a continued draw down.

The dramatic increase in O&M costs starting in 1998 and exacerbated after 9/11 is related to increased operational usage in the conflicts in the Middle East. FY11 O&M costs are nearly double those in 1998 in constant dollars. Roughly 20% of the increase is due to personnel costs. Additional contributing factors include increasing fuel costs (estimated at about a 25% increase over the last decade adjusted for inflation and about 12% of total O&M costs), increasing MDS complexity, and to a very limited degree, the impact of low observable materials on maintenance. The increased operational tempo and stressing flight profiles of the recent conflicts have increased effective flight hours (usage), and thereby O&M costs.

[23] Rehberg, C. "Air Force Aging Aircraft: An Old Saga with New Insights?"

As discussed previously, there have been several studies analyzing O&M costs to determine the contributing principal components, and specific to this study, identify the dependence of aircraft O&M cost on aircraft age. These studies analyzed O&M data for CPFH to normalize to usage rates. CPFH also accounts for the impact of varied flight profiles as flight severity factors are included to account for actual usage.

In summary, the cost to maintain these aging aircraft fleets is increasing, despite the decreasing size of the total fleet, and is reflected in the overall O&M costs realized by the Air Force.



The Air Force Sustainment Enterprise that has grown up around maintenance of Air Force aircraft is large and complex. Many players, not all shown in the diagram above, interface with the SPM and their Systems Program Office (SPO), from the Office of the Secretary of the Air Force (SAF) down to the maintainers on the flight line working on the Weapon System. The SPO is the driver of the process because the Air Force is MDS centric for sustainment execution. As the AF keeps weapon systems well beyond their original design service lives, the amount and extent of maintenance and modernization required for each weapon system requires the SPO to continually prioritize competing requirements to meet Mission and Operational MDS requirements.[24]

The SPO is organized to support a given aircraft. The MDS SPM, through the SPO, continually receives direction and inputs throughout the sustainment phase of the weapon system. In the chart above, the "Green Bubbles" represent the Headquarters United States Air Force (HAF) organizations that drive prioritization of requirements and distribute funding to the SPOs. Monies flow from the Office of the Assistant Secretary of the Air Force for Acquisition (SAF/AQ) for upgrades and from the Office of the Air Force Deputy Chief of Staff for Logistics, Installations, and Mission Support (AF/A4/7) for sustainment. SAF/AQ works directly through the Program Executive Officer (PEO) and the SPM while AF/A4/7 works through the HQ Air

---

[24] Arledge, E. "AF/A4L Perspective on Sustainment of Aging Aircraft."

Force Materiel Command Deputy Chief of Staff for Logistics (AFMC/A4) and the SPM. Often, the SPM may delegate the upgrade/development activities within the SPO to a Development System Office led by a Development System Manager (DSM) at AFMC's Aeronautical Systems Center (ASC). This structure allows the SPO and the Sustainment System Manager to focus on other sustainment duties. The delegation is based on complexity, funding, and workload of the modernization effort. As the weapon system ages, the FVB provides an independent assessment to the Secretary of the Air Force on the weapon system's remaining ability to maintain and fly effectively the Program of Record. FVB officials work closely with the SPO, as well as the Integrity Programs of ASC, in gathering the information required to perform the assessment, which includes examination of maintenance and depot records, cost of flying the aircraft, and weapon system effectiveness.

The "Blue Bubbles" represent the Lead MAJCOM organizations where the requirements and funding come for the sustainment efforts, eventually to the MDS SPM.[25,26,27,28] The appropriate MAJCOM, e.g., ACC, Air Education and Training Command, Air Mobility Command, Air Force Special Operations Command, or Air Force Global Strike Command, provides specific customer operational inputs and needs, which are then appropriately passed to either the PEO for major development activities or AFMC/A4 for support activities. These needs are translated into aircraft availability metrics used to measure the performance of the sustainment enterprise for the specific MDS. The PEO and AFMC/A4 direct the appropriate policy, requirements, and/or tasking in the execution of the efforts for the specific assigned MDS SPO.

For major upgrade efforts, the SPO will often utilize the Aeronautical Systems Center (ASC) within the PEO Chain to execute the development efforts as depicted in the "Light Blue Bubbles." A DSM is assigned with an MDS Development System Office for execution of the upgrade. In addition, ASC is responsible for working with the MDS SPO and the Sustainment System Manager in execution of the Life Management Phase of the Integrity Programs: Aircraft Structural Integrity Program (ASIP), Propulsion Systems Integrity Program (PSIP), Mechanical Equipment Systems Integrity Program (MECSIP), Avionics Integrity Program (AVIP), and Computer Systems and Software Integrity Program (CSSIP). The MDS SPO must interface with ASC, the independent Authority for Air Force Airworthiness for all MDS Aircraft. ASC provides and delegates portions of Airworthiness Authority to the SPO in obtaining and sustaining MDS Airworthiness.

The "Orange Bubbles" represent the core support and maintenance activities led by AFMC/A4. AFMC/A4 works with the MDS SPO from directing Command Policy to planning and executing Weapon System Sustainment (WSS) that includes Depot Purchased Equipment Maintenance activities, Contract Logistics Support (CLS), Technical Orders, and Sustaining

---

25 Collins, E., et al. "ACC briefing to SAB."

26 Aguilar, J. "AETC Briefing to the SAB on the T-38 Aircraft."

27 Colvard, M. "AFSOC Command Brief."

28 Air Mobility Command Directorate of Logistics. "AF Scientific Advisory Board Brief."

Engineering efforts. The SPM in turn directs the required task efforts to be executed at the Maintenance Wings and development and management of requirements of the Supply Chain, both the Air Force Global Logistics Support Center and the Defense Logistics Agency (DLA) in meeting MDS Programmed Depot Maintenance (PDM) schedules. The appropriate Maintenance Wing, located at one of the ALCs, executes the actual work on the MDS or component. The supply chain provides parts for field, organizational, and depot level activities. The SPO directs the requirements to the field and organizational levels which are accomplished by the appropriate User MAJCOM personnel, and the depot level which is accomplished by one of the ALCs. The SPO-managed depot level maintenance is accomplished through either organic efforts or the use of a CLS effort. The SPO and Maintenance Wings additionally develop and direct requirements and taskings to the Aerospace Maintenance and Regeneration Group (AMARG) which is responsible for the storage and regeneration of retired aircraft. The SPO and Maintenance Wings often take advantage of this resource for analysis of the weapon system in support of the remaining operational fleet and the use of cannibalization for critically non-available parts.

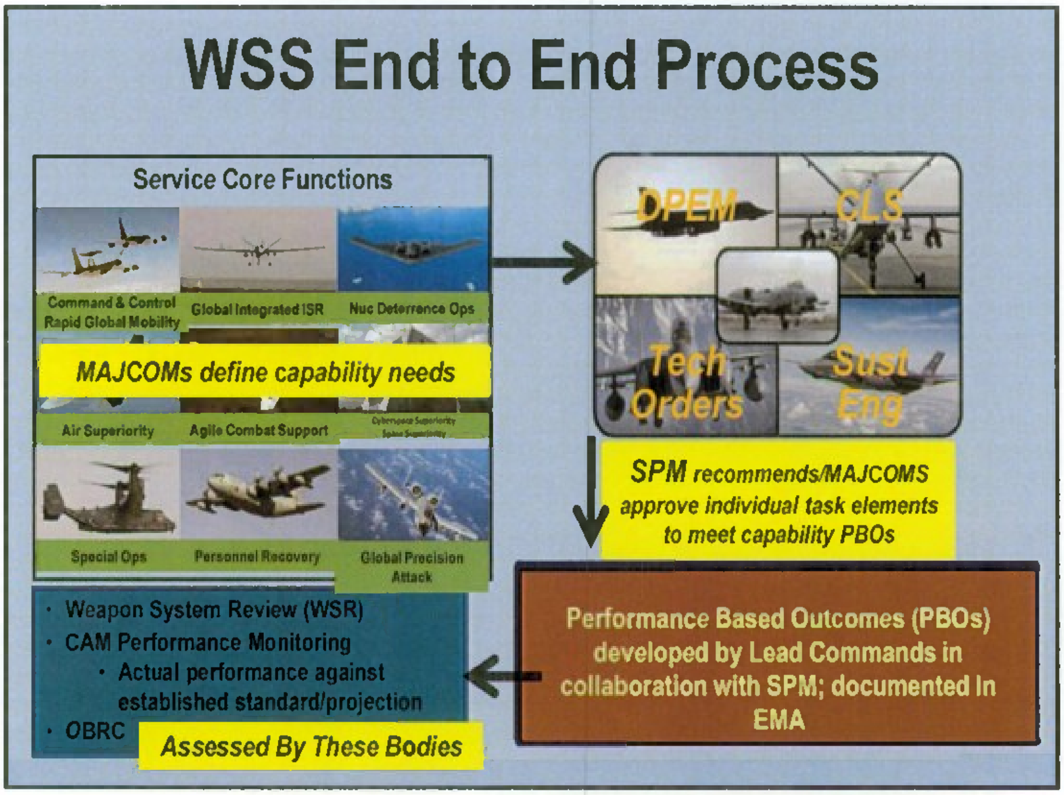


Figure 2-5. Weapon System Sustainment (WSS) Requirements Process.

Key in developing sustainment technology solutions for field, organizational, and depot maintenance is the Air Force Research Laboratory. The SPO provides sustainment needs to AFMC/A4 and AFRL to pursue the research and development projects required for weapon system viability. As the weapon systems remain in the fleet longer, developing mechanisms to enable the insertion of technology advances at high production readiness levels (Technology Readiness Level (TRL) and Manufacturing Readiness Level (MRL) of 9) is required for technologies related to inspecting, maintaining, re-engineering, and remanufacturing the MDS.

In 2006, the Air Force Chief of Staff directed the sustainment community to "radically simplify and streamline Air Force sustainment business practices." The result was to focus resources on AF priorities, as defined by the Air Force Corporate Structure, and as a result, the Centralized Asset Management (CAM) office was developed (Major General Kathleen Close, USAF, Deputy Chief of Staff for Logistics at AFMC, Personal Communication, January 12, 2011). The mission of the CAM office is to centralize and integrate management of Air Force sustainment to optimize warfighting capability through effective and efficient allocation of resources across the enterprise.[29]

Air Force Materiel Command was designated as the executive agent for Air Force Enterprise Sustainment. The CAM office guides the Weapon Systems Sustainment Planning, Programming, Budgeting, and Execution Process (Figure 2-5 above) through a well-defined, inclusive governance process.

The requirements development process first starts with the Lead Commands identifying their capability requirements in terms of Performance Based Outcomes (PBOs). Examples of capabilities requirements for the F-15C/D fleet, expressed in terms of PBOs, include providing 69.7% Aircraft Availability, completing 41 PDMs during the fiscal year, and assuring the APG-63(V1) radar has greater than 90% availability.[30] These capabilities are provided to the System Program Manager (SPM) who then works with the Lead Command and engineering community to document all needed tasks to deliver these capabilities. This process takes place in a fiscally unconstrained environment and forms the WSS requirement.

The CAM office uses the Annual Planning and Programming Guidance, the President's Budget, along with the PBOs and other known constraints, e.g., modification schedules and operations tempo, to determine specific allocations for each weapon system. The funding level allocated to each program is provided to the SPM for spread against the requirements.

This unconstrained WSS requirement is used by the SPM to recommend funds spread within their program to maximize capabilities to be delivered. At the same time, the SPM develops their funding proposal; they also develop capability buy backs. For the F-15C/D example, the SPM may state they can deliver 63% Aircraft Availability against the standard with funding provided; however, with an additional $15 million (M), they can improve Aircraft Availability to 67% (notional funding numbers).

The Lead MAJCOMs are provided the projected capabilities for all their PBOs as well as the buy-backs for all their weapon systems. They prioritize the buy-backs and provide those to the CAM office to submit to the Air Force Corporate Structure. This is transmitted as a Program Objective Memorandum (POM) submission to the HAF Logistics Panel.

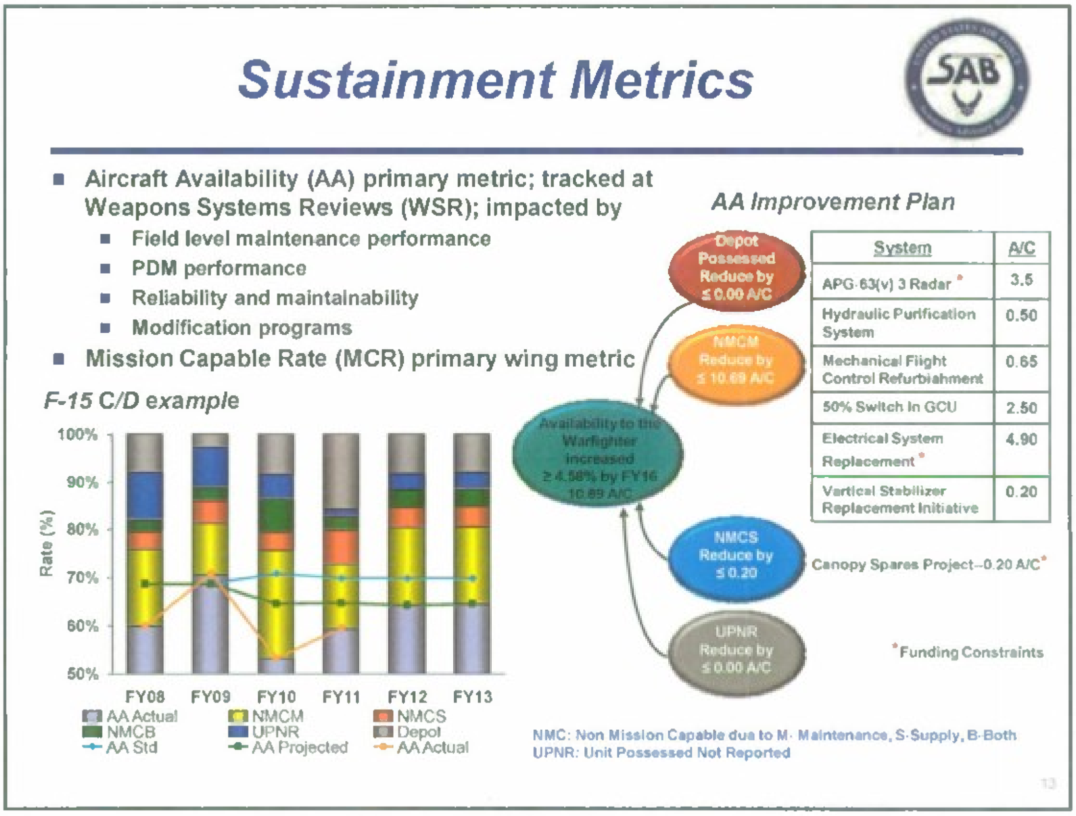
The Logistics Panel takes the WSS submission and defends it through the AF Board and AF Council where the request is vetted against other USAF requirements and the result of the AF POM submission to the Office of the Secretary of Defense (OSD). OSD performs analysis of

---

[29] Scaggs, J. "New System Streamlines Air Force Sustainment Funding."

[30] Swift, G. "Eagle Division AF Scientific Advisory Board."

each of the Services' budgets against national priorities and Department needs and ultimately sends to the Congress the President's Budget for their review and approval.



Aircraft availability is the primary metric used by the USAF today in determining the value of the PDM activities and processes. AA requirements are established by the Lead MAJCOMs in order to fill the mission plans of the Combatant Commands. They are used in Weapon Systems Reviews (WSRs) at the Chief of Staff of the Air Force (CSAF) level annually and are representative of PDM maintenance, reliability, and maintainability of each MDS, and the status of the modification programs that are funded for the MDS. Weapon System Reviews (WSRs) are performed quarterly at the AFMC level for each MDS as well. Metrics for these reviews differ from those for the aircraft operational wings. Their primary metric is mission capable rate, i.e., the percentage of the wing possessed aircraft that are mission capable.

The chart above displays the kind of data reviewed by the CSAF at a WSR. For each MDS (F-15 data are shown as an example here), the target level of availability is reviewed and reconfirmed.[31] The level of availability previously projected is reviewed and often, as shown, this level is lower than the targeted level. The actual aircraft availability history is the lowest of the lines shown on the chart and provides a status of the current number of aircraft available for combat missions.

In each bar, the components that detract from aircraft availability are shown. These include non-mission capable due to supply (NMCS), non-mission capable waiting on

---

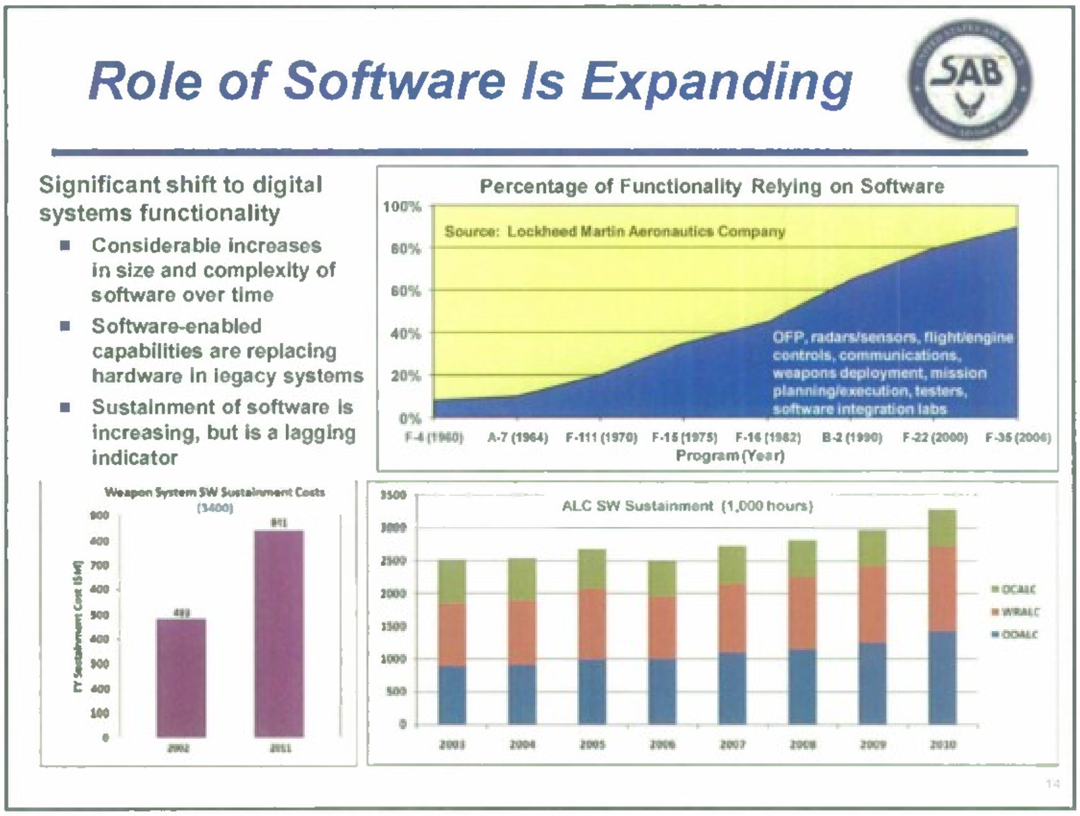
[31] Swift, G. "Eagle Division AF Scientific Advisory Board."

maintenance (NMCM), non-mission capable due to both maintenance and supply (NMCB), grounded aircraft in the field (Unit Possessed but Not Reported – UPNR), and aircraft at depot awaiting maintenance (Depot Possessed). All of these affect aircraft availability and negatively impact the USAF's ability to meet its availability targets.

On the right hand side of the chart is the plan for restoring the aircraft to its availability target. These plans typically include activities to reduce the number of aircraft in depot (Depot), the number of aircraft Unit Possessed but not reported (UPNR), the number of aircraft awaiting maintenance (NMCM), and the number of aircraft awaiting supplies (NMCS). As shown, this particular plan has actions in place to address the NMCM cause, but none of the others. Several actions noted on the right side of the chart seek to restore the NMCM rate for the aircraft by more than 12-13 aircraft/year. However, funding limitations reduce that number to less than 11 per year.

These charts and supporting data are reviewed by AFMC continuously throughout the year, reviewed once a quarter by the AFMC Staff, and once per year by the CSAF. From them, decisions are made on funding to recover availability where needed, through acceleration or delay of certain maintenance actions, revision to operational plans, or contingencies determined by the number of mission capable aircraft available at various bases.

These actions made to increase availability include both hardware and software maintenance and upgrades. It is expected that software maintenance and upgrades will grow in the future as the F-22 and F-35 see regular operational service and as more software driven components are implemented in legacy aircraft.



USAF weapons systems have shifted from analog to digital systems functionality over the past six decades. This shift, coupled with other trends (such as Moore's Law, commercial development, expanded threat spectrum, diminished manufacturing sources (DMS)-driven interfaces), has caused the role and importance of software to expand significantly for the DoD in general and the USAF in particular. These themes of the growing importance of software in the DoD and the USAF are discussed at length in a recent report from the National Research Council.[32] The chart above shows software sustainment elements from a variety of sources.[33] For example, the diagram on the upper right above shows an example of how much USAF system functionality relies on software, as measured by the percentage of specification requirements involving software control, which has risen from approximately 8 percent of the F-4 in 1960, to 45 percent of the F-16 in 1982, to 90 percent of the F-35 in 2006.[34,35,36]

---

[32] National Research Council. "Critical Code: Software Producibility for Defense."

[33] Defense Science Board. "Report of the Defense Science Board Task Force on Defense Software."

[34] Lockheed Martin Aeronautics Company. "Software Functionality in Acquisition."

[35] Boehm, B., Lane, J., Koolmanojwong, S., & Turner, R. "Architected Agile Solutions for Software Reliant Systems."

Software has become essential to all aspects of USAF system capabilities and operations, including the Operational Flight Program (OFP), radars/sensors, flight/engine controls, communications, weapons deployment, mission planning/execution, testers, program lifecycle management systems, and software integration labs. Although software does not "wear out," firmware becomes obsolete and consequently software must be modified to run on new components. Likewise, upgraded digital capability must be integrated into existing digital systems and software defects will continuously be identified and fixed to allow full functionality. It is therefore not surprising that the USAF is expending an increasing amount of time/effort sustaining software, which (according to a working definition used by the Software Engineering Institute) involves: the processes, procedures, people, and information/databases required to support, maintain, and operate the software aspects of USAF weapons systems.[37]

For example, the diagram (lower left in the previous chart) shows that total weapon system software sustainment costs have doubled in less than 10 years. Likewise, the same chart (lower right diagram), shows an increase in software sustainment hours at the three ALCs over the past eight years.

Moreover, although software sustainment costs have increased at the ALCs, it is a lagging indicator, which suggests that future software sustainment costs will grow significantly as the current generation of more software-reliant aircraft transition from production to sustainment.

Although the terms software sustainment and software maintenance are often used interchangeably, there are important distinctions between them.[38] In particular, software maintenance consists of correcting faults, addressing loss of original part supplier issues, and adapting software to a changed environment. Software sustainment goes beyond software maintenance to also address other issues not always included in maintenance, such as improving performance or other attributes, operations, documentation, deployment, security, configuration management, training, help desk, COTS management, and technology refresh.

It is also important to recognize the distinctions between hardware and software sustainment—software is not sustained in same way as hardware on USAF aircraft.[39] In particular, when hardware fails, the failed part is typically replaced with an identically functioning part. In contrast, when software fails, sustainment is performed and tests run to verify that the revisions work.

---

[36] "Exponential Software Growth in Fighters."

[37] Lapham, M., & Woody, C. "Sustaining Software Intensive Systems."

[38] Lapham, M. "Sustaining Software Intensive Systems – A Conundrum."

[39] United States Air Force Software Technology Support Center. "Guidelines for Successful Acquisition and Management of Software-Intensive Systems: Weapon Systems, Command and Control Systems, and Management Information Systems (Condensed Version)."

There are four primary types of software sustainment activities:[40]

- Corrective Sustainment – diagnosis and correction of program errors after its release.
- Perfective Sustainment – the addition of new capabilities and functionality to existing software.
- Adaptive Sustainment – modification of software to interface with a changing environment.
- Preventive Sustainment – modification of software to improve future maintainability or reliability.

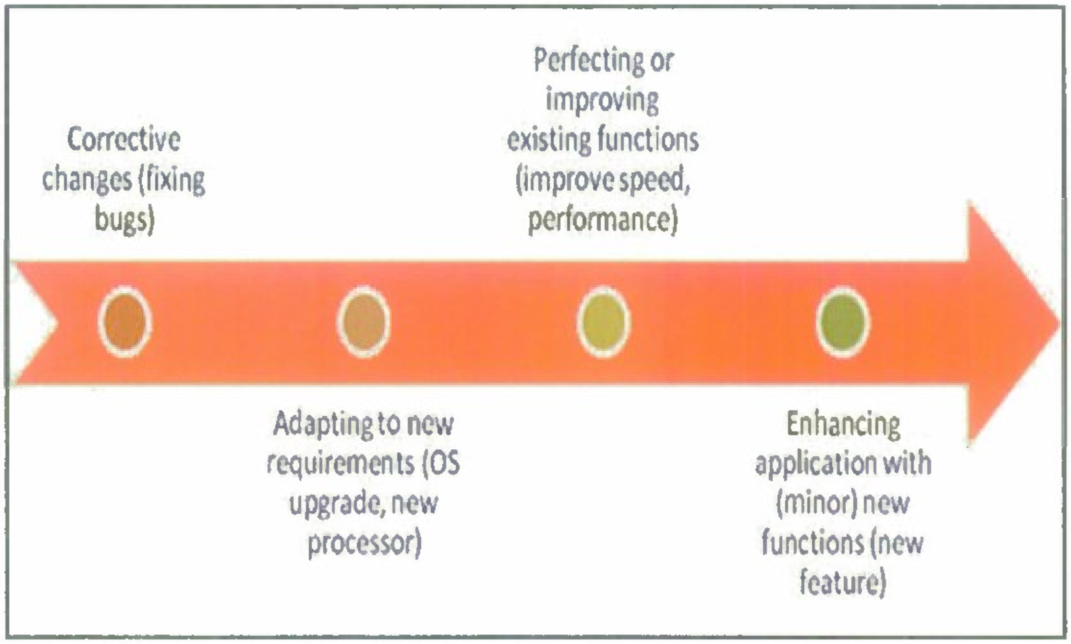


Figure 2-6. Software Sustainment Life Cycle. Note: This depiction was found via the Journal of Software Technology.[41]

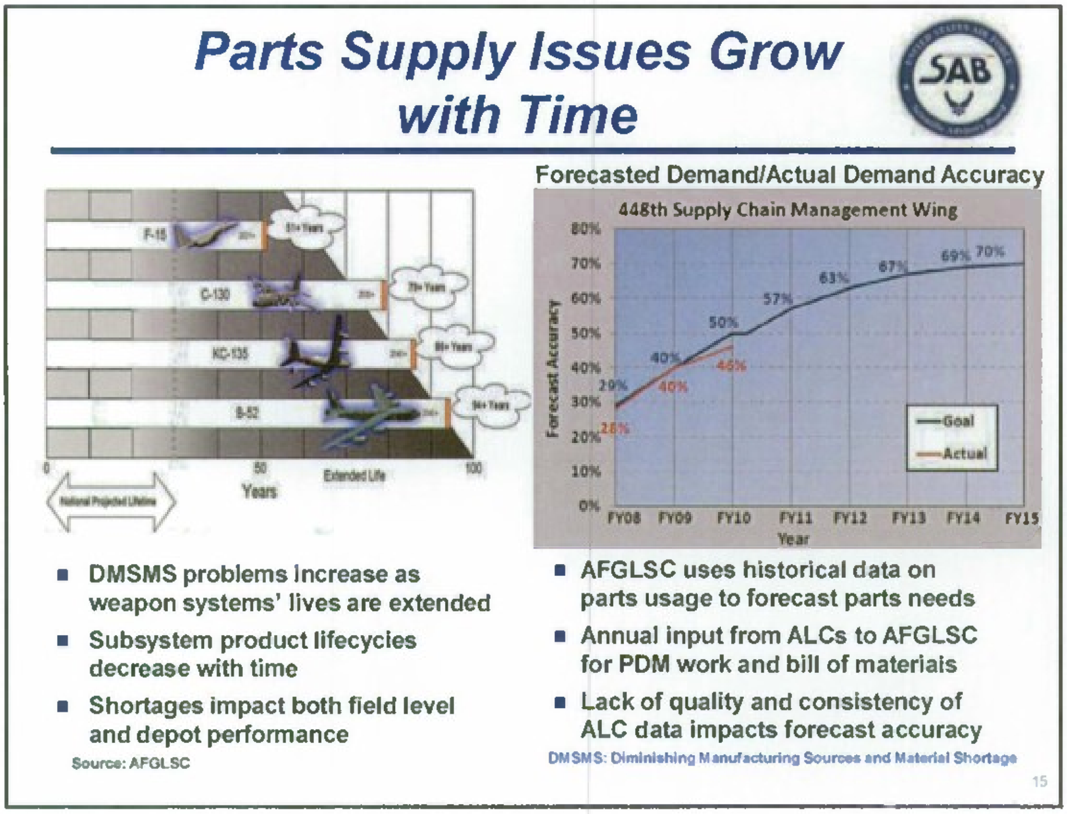
It is also generally recognized that software evolution (defined as increasing functionality to meet new requirements) is inevitable, expensive, and hard.[42] It is possible to increase the sustainability of a software system by designing it properly in the first place. Sustainment typically accounts for 75% or more of the total software workload. The cost is driven by the development quality and highly dependent on maintenance rigor and operational "life expectancy." The activities of sustainment shown in Figure 2-6 (above) generally include sustaining engineering and new function development.

---

[40] Ibid.

[41] Galorath, D. "Software Total Ownership Costs: Development is Only Job One."

[42] Krasner, H. "Legacy Software Maintenance Improvement: Where is the Payoff?"



The left figure on the chart shows the original planned life for the F-15, C-130, KC-135, and B-52 along with their extended service lives.[43] The plan for sustainment and replacement parts was based on the original projected life of the aircraft; however, as the life of these aircraft has more than doubled, the original parts strategy has become inadequate. Moreover, as legacy MDS sustainment is made organic, Original Equipment Manufacturers (OEMs) tend to move on to new technologies and products aligned with new procurements or upgrades. This has often resulted in the OEMs, and their second and third tier suppliers, no longer being available as a supplier of replacement parts or materials for fielded aircraft thereby causing Diminishing Manufacturing Sources and Material Shortages (DMSMS). As suppliers diminish, the sustainment enterprise relies more heavily on cannibalizing parts from grounded aircraft and on the commercial parts sector. But, commercial part lifecycles are very short compared to Air Force aircraft lifetimes and the subsequent decrease in product lifecycles times, especially for commercial electronics, also contributes to increasing DMS occurrences.

Dealing with the DMSMS issues requires an enterprise approach to supply chain management that is the responsibility of the AF Global Logistics Support Center (AFGLSC) as well as the Defense Logistics Agency (DLA). In addition, sustainment engineering is involved with each MDS in developing the PDM work tasks and bill of materials while considering

---

[43] Burke, L., & Hughes, G. "Sustaining Aging Aircraft: DMSMS & Sustaining Engineering."

DMSMS and obsolescence issues. The Air Force uses a software tool developed by BAE Systems, the Advanced Component Obsolescence Management (AVCOM) predictive tool for proactive assessments. While AVCOM is broadly available within the ALCs, it is not uniformly used across the enterprise. Assessment of obsolescence and DMSMS early in the maintenance and supply chain process is critical to allow proactive resolution of issues and minimize the impact on depot productivity.

An indication of the magnitude of DMSMS issues confronting AFGLSC is shown in Figure 2-7 below.[44] It displays the number of obsolete parts for which AFGLSC needs to find replacements. As can be seen, over the last few years solutions have been found for approximately 18,000 obsolete parts while solutions remain to be found for about 42,000 thousand other parts, a growth of 10% over just the last year.

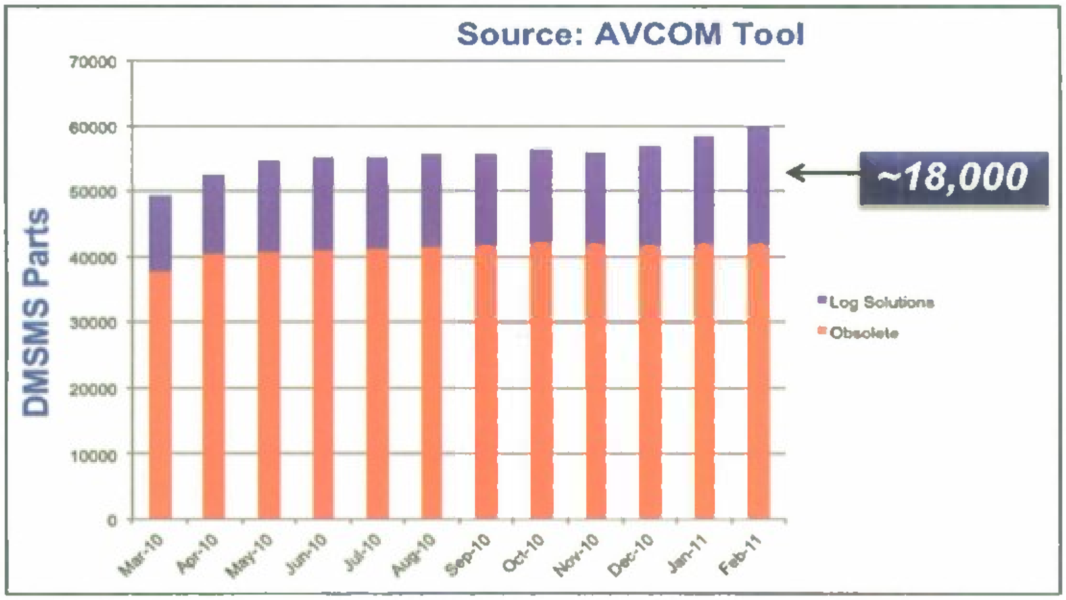


Figure 2-7. AFGLSC Needs to Obtain and Increasing Number of Obsolete Parts.

AFGLSC is responsible for delivering integrated global supply chain support for warfighter capabilities for the Air Force. They are the Engineering Support Authority for approximately 400,000 National Stock Number parts for the DLA, own and manage 140,000 parts, and are responsible for 25,000 Technical Orders.[45] Key to this is the ability to forecast supply chain requirements. To do forecasting, AFGLSC uses an organically developed software tool: D200A, Secondary Item Requirements System. D200A contains historical parts data from field and depot maintenance. This is used to forecast the needs for future PDM and field maintenance actions. The right-hand figure on the previous chart shows current supply chain

---

[44] Ibid.

[45] Ibid.

forecasting accuracy along with the projected improvements for the 448th Supply Chain Management Wing under AFGLSC.

Demand Forecast Accuracy (DFA) is calculated as shown in the equations below.

- DFA – a measure of how well future usage of an item (NSN) is estimated

$$DFA = 1 - \frac{|\text{Actual Demand} - \text{Forecast}|}{\text{Actual Demand}}$$

- Aggregate DFA – a measure of how well future usage of a group of items (NSNs) is estimated

$$DFA = 1 - \frac{\sum |\text{Actual Demand} - \text{Forecast}|}{\sum \text{Actual Demand}}$$

Figure 2-8. Demand Forecast Equations.

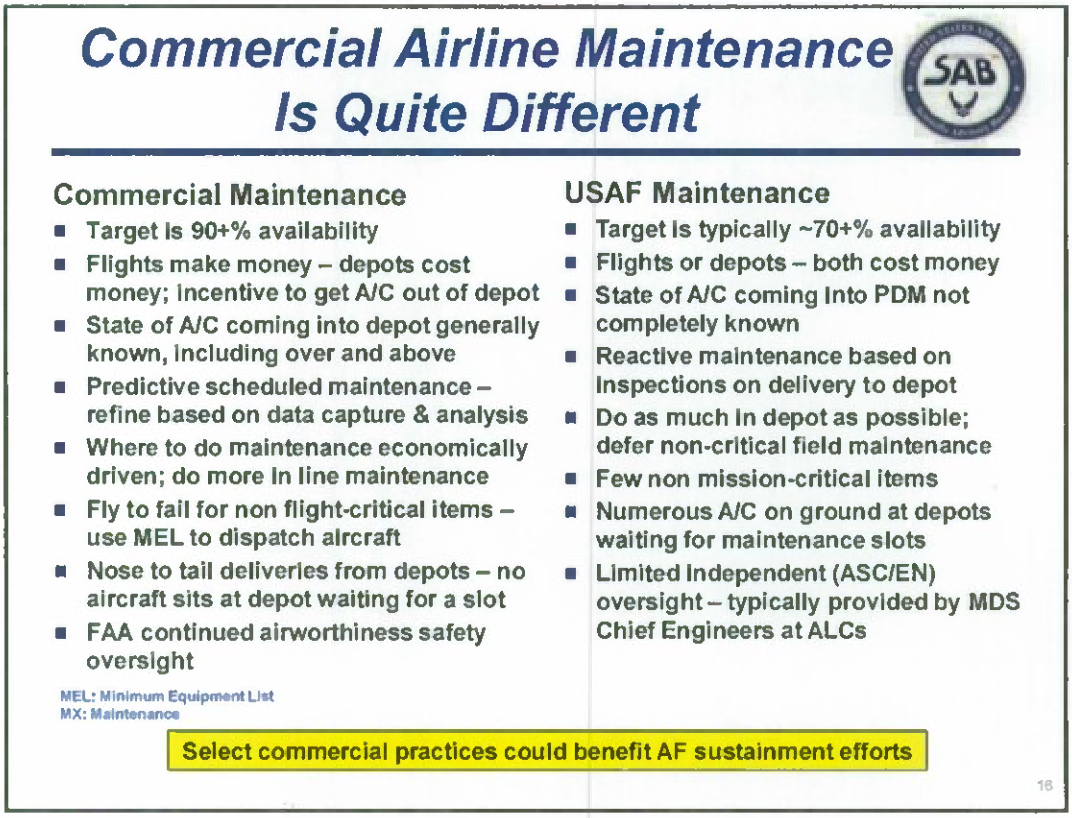
DFA is determined at Fiscal Year-end by comparing Actual Demand (measured at year-end) to Forecast Demand (from beginning of year). Both over and under forecasting is considered in measuring accuracy. DFA was as low as 29% in FY08 and improved to 46% for FY10. AFGLSC has a plan to improve DFA to 70% by end of FY15. Forecasting accuracy represents a significant short fall for AFGLSC overall.

To feed forecasting, the supply chain requirements are developed under the annual Air and Missile Requirements (AMR) process. The initial PDM work task definition is done through the Engineering Requirements Review Process (ERRP) that develops requirements for each MDS and then approves and determines supportability of scheduled maintenance tasks. The ERRP output flows to the AMR work specification and then to the AMR brochure. The AMR brochure documents requirements to the supply chain to include AFGLSC and DLA. These AMR requirements are used to forecast the parts requirements for the following 5 years. Supportability (i.e., DMSMS) is addressed by the AFGLSC and DLA with an emphasis on a 1-3 year horizon.

The problem with supply forecasting comes in many cases from the lowest level of data entry. Too often data are entered at such a high level that it is not useful for determining what parts were used or needed. Other times, the wait for parts is such that the depot will simply recreate the part in the backshop and not order it. In those cases the part is not registered and so the AFGLSC never knows that the part was needed or used. This unfortunately happens often enough to throw the parts inventory and forecasting system off for the next year at least. Boeing, in supporting the C-17, has begun to check the maintenance records against the parts ordered to "clean" the maintenance and parts lists so that they agree to a much higher level of fidelity than what is recorded by the maintenance personnel. To show the extent of the problem (and

realizing that these not only contribute to the parts forecasting issue but to many other issues as well), the SAA Study Panel was told[46] that Boeing cleans 40,000 records a month using an automated parts and ticket tracking system.

[46] SAA Study Panel visit to The Boeing Company, Saint Louis, MO, March 11, 2011.



There are numerous differences between the maintenance practices used by the commercial airlines and the Air Force. These are compared and contrasted in the following paragraphs.

Aircraft Availability

Aircraft Availability is defined as the percentage of a fleet's TAI (unit and depot possessed) that are mission capable.[47] Mission capable means that the aircraft is available to be scheduled for a mission.

Commercial airlines require a high AA to meet revenue and profit objectives. Put simply, a plane that is not flying produces no value for an airline. To this point, commercial aircraft average nearly 12 flight hours/day. Typically, between 3% and 8% of the aircraft at a commercial airline are out of service for maintenance at any time (R. Valieka, former Senior Vice President of TechOps for Delta Air Lines and C. R. Kizer, former President and Chief Operating Officer of Airbus North America-Customer Service, Personal Communication, May 18, 2011). This corresponds to an AA target greater than 90%.

[47] Aguilar, J. "AETC Briefing to the SAB on the T-38 Aircraft."

The Air Force AA rates vary by MDS, but are typically on the order of 70%. Based upon briefings to the Panel, AA goal standards for selected MDSs are shown below:

- C-5: 68%[48]
- C-130: 67%[49]
- F-15: 70%[50]
- KC-135: 76%[51]
- B-52: 62%[52]
- A-10: 71%[53]
- T-38: 58%[54]
- F-16: 69%[55]
- C-17: 75%[56]

Quite a few MDSs are not meeting their AA standards currently. Further, several MDS were projected to be below AA standards well into the future.

Aircraft State Coming into Depot Maintenance

The term "over and above" is used to describe additional maintenance work required on an aircraft that is discovered after the maintenance has been started. Over and above accounts for a significant percentage of the cost and time required for aircraft depot maintenance visits and grows with aircraft age. Over and above also accounts for a large amount of the depot visit cycle time variability.

Commercial airlines typically have a good idea of the amount of over and above work that is required when an aircraft visits a depot for maintenance (Valicka & Kizer, Personal Communication, 2011). This is likely due to the fact that commercial airlines are highly data focused, maintain aircraft regularly in service, track the maintenance process closely, and have highly predictable flight profiles. Detailed data tracking and analysis allows the airlines to continuously learn and refine the maintenance process throughout the life cycle of the aircraft. This effort allows a predictive nature of the over and above required.

The Air Force appears to have a lower level of knowledge about the aircraft state coming into the depot than do the commercial airlines. The reasons for the Air Force having less

---

48 Gregg, M. "C-5 Galaxy Division."

49 Tribble, G., et al. "Tactical Division AF Scientific Advisory Board."

50 Swift, G. "Eagle Division AF Scientific Advisory Board."

51 Air Mobility Command Directorate of Logistics. "AF Scientific Advisory Board Brief."

52 Smith, J. "B-52 Scientific Advisory Board (SAB) Briefing."

53 Hebert, G. "Scientific Advisory Board A-10 Briefing."

54 T-38 AA rate provided by Lieutenant Colonel Amanda Myers, Oklahoma City Air Logistics Center Aerospace Sustainment Directorate, via Personal Communication, June 14, 2011.

55 Sutton, D. "F-16 System Program Office."

56 Air Mobility Command Directorate of Logistics. "AF Scientific Advisory Board Brief."

knowledge about the aircraft are not clearly known, but likely lie in the difference between data collection and analysis techniques previously described, the fact that so much field level maintenance is deferred to depot, as well as flight profile histories that can vary significantly by aircraft tail number. Data collection in the Air Force is spread across numerous databases that are not integrated[57] and, in some cases, not easily searchable. There are also questions about the accuracy and validity of the Air Force reliability data.

The C-130 High Velocity Maintenance (HVM) project is sending advance teams out to perform inspections on the aircraft prior to delivery to the depot.[58] The intent of this effort is to conduct a few days of inspections (without aircraft disassembly) using borescope and other tools to assess likely areas that will require repairs or maintenance. Benefits from this include the opportunity to order parts earlier and also better understand the maintenance work scope. This practice appears promising and appears to be an opportunity for improvement if the Air Force expanded its use across all MDSs.

Maintenance Schedules

As previously discussed, commercial airlines emphasize reliability and maintenance data capture and analysis (Valieka & Kizer, Personal Communication, 2011). They use this information to continuously refine and improve their maintenance processes. This allows the airlines to perform a significant amount of maintenance in a predictive fashion where issues are resolved prior to actual failures occurring.

Air Force maintenance processes vary widely by MDS, but appear to be more reactive than those of the airlines. Reactive in this sense means that the Air Force maintenance is based more on inspections of the aircraft and reacting to what is learned rather than using historical and field level data to predict and implement maintenance. Improving field level and reliability data capture and analysis appears to be an opportunity for the Air Force to improve their future maintenance practices.

Where and When Maintenance is Performed

Commercial aircraft heavy maintenance is completed at either an airline's internal facility (typical for large airlines) or a Maintenance, Repair, and Overhaul (MRO) facility. The Air Force conducts heavy maintenance at one of three ALCs: Warner Robins, Oklahoma City, and Ogden.

Commercial airlines perform maintenance at locations and times based on the most economical opportunities. In practical terms, this means that airlines conduct a larger percentage of their maintenance in the field versus at a maintenance depot (K. Davis, Personal Communication, March 24, 2011). Typically, this maintenance is performed with a large and experienced maintenance staff during an overnight layover.

---

[57] Gregg, M. "C-5 Galaxy Division."

[58] Tribble, G., et al. "Tactical Division AF Scientific Advisory Board."

In contrast to the airlines, the Air Force prefers to minimize maintenance completed in the field. When possible, maintenance is deferred until a depot visit. One reason for this Air Force strategy is related to the experience level of field maintenance personnel. In contrast with the airlines, most field maintenance personnel are Air Force mechanics with lower levels of experience than their commercial counterparts, some of this resulting from Program Budget Decision 720 (issued in FY 2006). Another reason is that it is very difficult for the Air Force to deliver spare parts in theatre. Deferring the maintenance to the depots allows more experienced mechanics to do the work and is believed by the Air Force to be more cost effective.

Parts Replacement Strategies

Commercial airlines typically use the MSG-3 (Maintenance Steering Group – 3) process to classify part criticality and use reliability data to determine maintenance replacement strategies (Valieka & Kizer, Personal Communication, 2011). This process, the many non-mission critical systems, and the typical redundant design of commercial aircraft, allow many parts to "fly to fail." The airlines avoid delayed or cancelled flights using the Minimum Equipment List (MEL), which is a Federal Aviation Administration (FAA)-approved pre-determined list of the minimum operating parts which are required to dispatch the aircraft. The essence of this strategy is that the aircraft can be dispatched for a limited number of flights that allows continued operation until the next maintenance visit where the failed part is then replaced.

The Air Force fleet typically has more mission critical equipment than an airline. Further, the Air Force prefers to do the majority of their maintenance at the depots. This limits their ability to use the fly to fail parts replacement strategy. However, there are systems in which the strategy could be used effectively, such as thrust reversers, cabin pressure controls, air turbine starters and start valves, auxiliary power units, secondary electronic devices, environmental control system packs and valves, engine controls (e.g., full authority digital engine controls). Not all USAF aircraft have these systems, but those that do could use the fly to fail strategy.

Number of Aircraft at Depot

As previously discussed, commercial airlines require high AA rates to maximize their revenue. Since aircraft in depot are not available, they directly impact AA rates. This forces airlines to carefully schedule aircraft into depots and forces depots to minimize cycle time, to ensure that very few aircraft are at depot waiting for maintenance. Another way to look at this is that, for the airlines, flights make money and depots cost money. This provides a natural incentive to minimize the number of aircraft and time spent at the depot.

The Air Force, given their interest in lowering maintenance costs and willingness to accept lower AA targets, allows significant numbers of aircraft to be at the depot. This was seen during visits to the ALCs where numerous aircraft were seen without active maintenance being performed on them. This situation is different than for an airline, which plans depot schedules so that the next aircraft to be worked is wheeled into depot as the previous one is wheeled out with as few aircraft awaiting slots as possible.

Airworthiness

Continued airworthiness for the commercial airlines is required by FAA regulations and managed by the airlines under the oversight of the FAA. This independent oversight ensures regulations are complied with and helps to drive the extremely high safety level currently demonstrated by the airlines. The Panel was informed that the FAA also has the authority to mandate changes in design or maintenance practices to ensure aviation safety.[59,60]

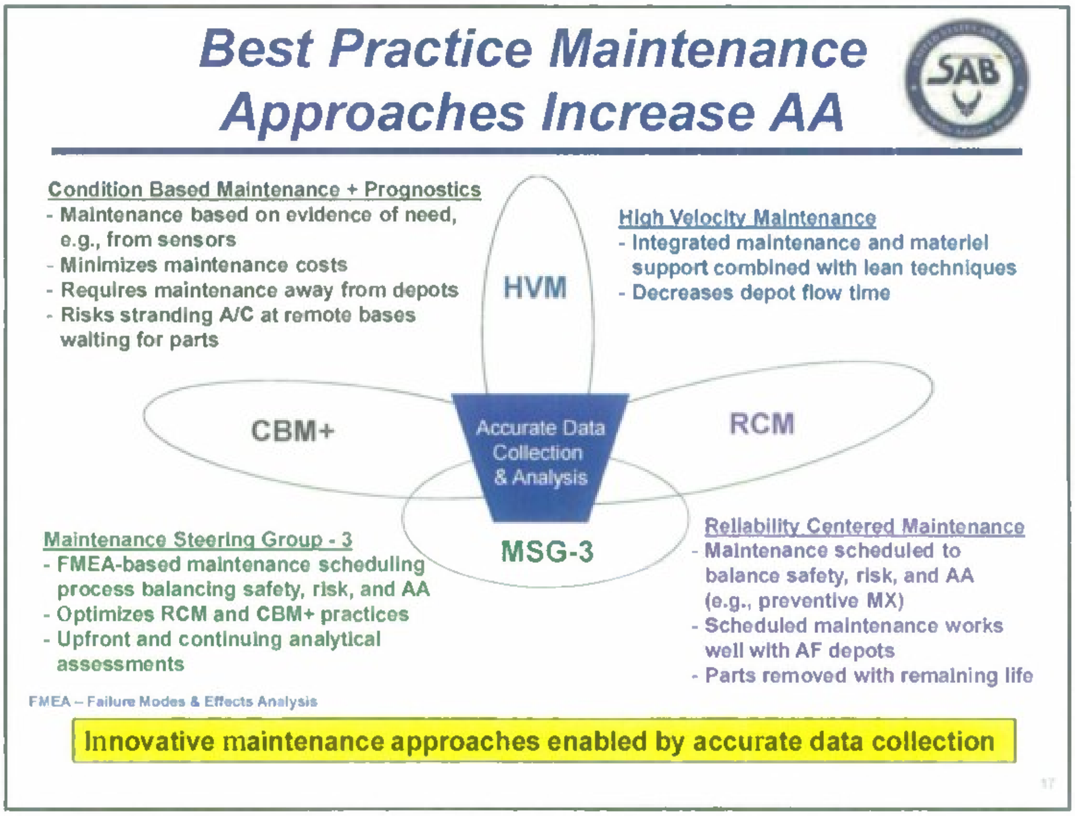
The Study Panel, in comparing the USAF airworthiness determination and oversight processes with those of the FAA, notes that both use a similar structure for determining and maintaining oversight of airworthiness. The Air Force's airworthiness process is managed through the Engineering Directorate at the Aeronautical Systems Center (ASC/EN) airworthiness organization.[61] However, this group has only recently been given this authority, and, based on the Panel's visits to the three ALCs, has limited oversight over continued airworthiness decisions made on the MDSs. The Panel noted that for most weapon systems, the various MDS Chief Engineers appear to be more directly involved in airworthiness decisions than ASC/EN.

---

[59] SAA Panel visit to the FAA Transport Airplane Directorate, Renton, WA, May 23, 2011.

[60] Title 49 United States Code, Section 106 (Federal Aviation Administration), Subsection g (Duties and Powers of Administrator), and Title 14 Code of Federal Regulations, Part 39 (Sections 39.1, 39.3, 39.5, 39.11, and 39.13)

[61] Grimsley, F. "USAF Airworthiness Process Overview: Presentation to Scientific Advisory Board."



There are several maintenance practices used by the commercial aircraft industry and the Air Force. Each of these is described in the following sections. A key element to all of these approaches is accurate data capture and analysis. Reliability data must be properly entered by the maintainers by Work Unit Code (WUC) and then analyzed to facilitate these maintenance approaches. The Air Force currently has issues with both the accuracy of this data and the availability of analysts to properly analyze it. Commercial airlines place a high value on both of these areas to ensure they are receiving the maximum value from their maintenance plans.

Condition Based Maintenance + Prognostics (CBM +)

A condition based maintenance strategy performs maintenance when there is an evidence of need based on data from sensors or through off line trend monitoring. This strategy can minimize maintenance costs since no "extra" maintenance is performed, i.e., parts are allowed to remain on wing for their full lives. The "+" stands for prognostics which is a feature intended to use real time sensor data to predict anomalies and remove components prior to failure.

CBM is heavily used by airlines which have aircraft specifically designed to be operated with some systems inoperative. The airlines typically use the MEL to determine if the aircraft can be dispatched with an inoperative system. In addition, commercial aircraft are typically designed with Time Limited Dispatch, which allows the aircraft to be operated for a specific period of time with some systems inoperative.

CBM poses risks and challenges for the Air Force since maintenance needs to be performed when the condition arises. This means that maintenance may occur at remote bases

where parts availability and mechanic experience may be less than what is available at a depot. Utilizing this approach could result in Air Force aircraft waiting for parts while in theatre or requiring experienced crews to travel to the aircraft to make repairs.

High Velocity Maintenance

The Air Force has high velocity maintenance pilot programs underway at Warner Robins ALC for the C-130 and Oklahoma City ALC for the B-1B. These programs are integrating work scope, work procedures, required tools, and parts to ensure that maintenance is performed in an efficient manner. The objective is to ensure that the mechanics have all the tools, manuals, and parts to complete their daily work without leaving the aircraft. HVM is essentially applying lean techniques to the maintenance process.

HVM uses pre-induction inspections or inspections upon receipt of the aircraft to determine what maintenance beyond that scheduled (above and beyond) will be necessary. If such additional maintenance actions are required, then parts are ordered and tasks begin to be readied to cover these additional actions. The combined scheduled maintenance and component upgrades are intended to have been previously prepared and kitted into daily work actions that are waiting for the actions to take place as scheduled. If parts ordered are received by the time that scheduled actions in the area have been completed, then these additional above and beyond actions do not add much time to the scheduled depot time. But, if they are not so delivered, then the aircraft is down and multiple actions begin to mount each day that the parts are delayed. The penalty can be high. Thus HVM is completely dependent on good scheduled maintenance, upgrade planning and pre-induction inspections, or field maintenance actions recovered well enough in advance that no wait time is incurred by the system.

Reliability Centered Maintenance (RCM)

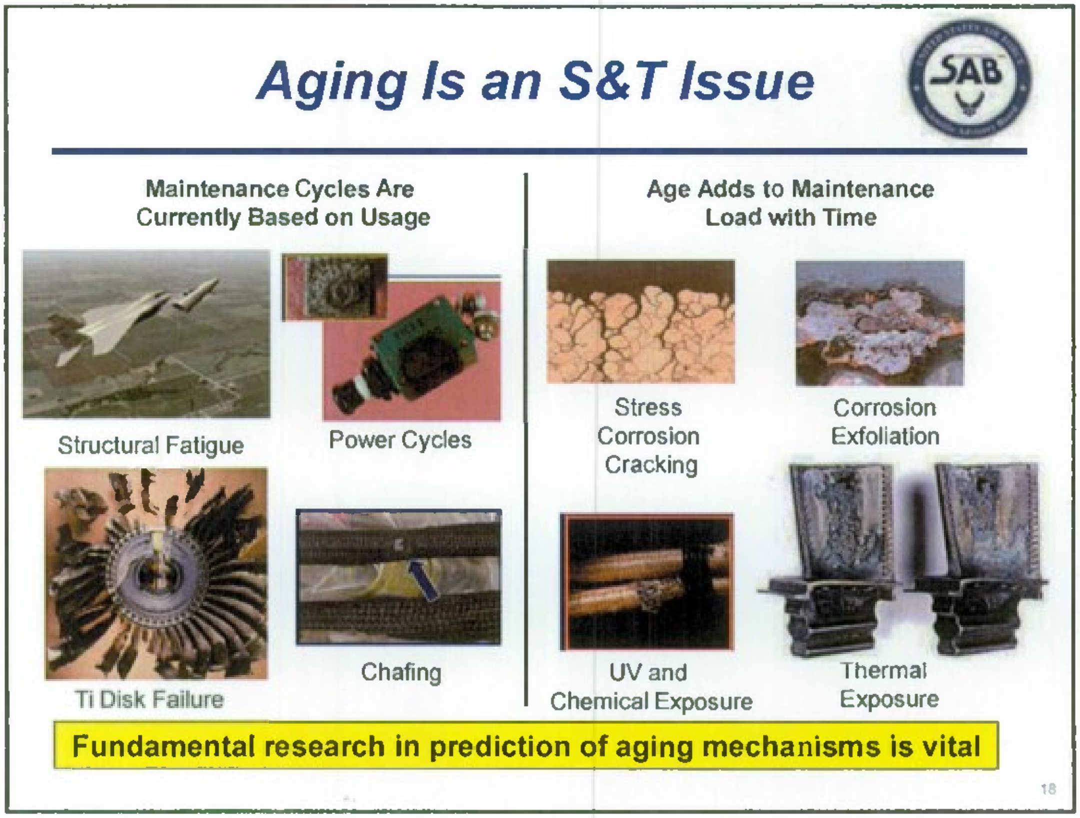
RCM uses reliability tools and techniques to schedule maintenance to balance safety, schedule, and risk by assembling the probability distributions for parts failures. As previously stated, accurate reliability data capture, especially in the field, and subsequent analysis are the foundations of the RCM approach. RCM has been applied successfully in the past across various USAF MDSs, but has waned recently in some areas. RCM typically increases maintenance parts costs since it is preventive and some components are replaced prior to failure and have useful life remaining. This cost is offset by lowered aircraft downtime due to reduced component failures in service and significant reductions in wait time for undelivered parts.

MSG-3

MSG-3 is the standard practice used by commercial airlines for aircraft maintenance. The MSG-3 program begins as the aircraft enters service and is continually updated throughout the aircraft lifecycle. MSG-3 uses the Failure Modes & Effects Analysis technique to balance safety, schedule, and risk for the maintenance process. This practice combines both condition based and reliability centered maintenance practices.

One of the key features of the MSG practice is that maintenance and inspections for all systems in a given area of the aircraft are made while the aircraft is open for one system maintenance action, so that all the maintenance in that area can be performed. This minimizes

the number of times a given area of the aireraft must be opened up for maintenanee and generally provides for longer lasting proteetion systems and redueed effeets of aging.



Maintenance cycles are generally based on the fatigue life of structures and mean time between failures of systems. These lives are determined by design and validated by testing to provide the maximum safe life possible before failures become prevalent and degrade the function of the system to the point at which safety is compromised. Maintenance cycles are prescribed by plan to ensure safety by performing inspections at the half-life and performing replacement and repairs as required by either inspection or failures. This plan is generally able to maintain safety of flight for the aircraft until either its usage exceeds its design service life or its age exceeds the age associated with its design service life. In general, at the time that many of our legacy aircraft were designed, they had no explicit design service life or age defined. More recent legacy aircraft were designed to a specific service life, but this life was not fully validated by test. In recent years, ASIP activities filled this gap by applying analytical and full-scale fatigue testing to establish design service life.

Examples of cyclic-driven failure modes are shown in the above chart and described below:

- Upper longeron failure in an F-15, that caused the cockpit to separate from the rest of the airplane. This longeron failed by fatigue, although the root cause was a

manufacturing defect in which the longeron was machined to a thickness below minimum specification.[62]

- On-off power cycles for electronic components cause fatigue failure as the expansion and contraction induced by heating, and physical constraints within the devices, lead to stress concentrations and subsequent failures.[63]
- Wiring bundles flex as the aircraft does maneuvers, and fretting/chaffing can occur when wires rub against one another or rub on penetrations through the aircraft structure.[64]
- Disks are designed to a specific fatigue limit, and they may be operated for longer periods using fracture mechanics analysis. However, disk life can be shortened if there are manufacturing defects within the disks that act as stress concentrators.[65]

As legacy aircraft age, there are failure modes that occur due not to usage, but simply due to aging of the aircraft in its station environment. These aging degradations occur at different rates depending on the viability of the corrosion prevention systems, the sealants and primers, and the aggressiveness of the environment in which the aircraft are stationed (seaside being worse than inland for example). It should be noted that the push to go from the chromate-hased primers to more environmentally benign primers results in less protection for newer aircraft than has been seen in the legacy fleet. These first generation sealants are being replaced by more effective second generation non-chromate primers for future aircraft and repairs to legacy aircraft where applicable. Still, all sealants and corrosion barriers eventually break down in aggressive environments.[66,67]

Aging materials see degradation without load from a number of different sources: chemical, thermal, ultraviolet, and moisture. Today's chemical modeling capabilities allow prediction of the effects of moisture and other chemistries on the degradation of materials based on their chemistries and the environment. The same chemical modeling can be used to evaluate

---

[62] United States Air Force. "Executive Summary: Aircraft Accident Investigation F-15C, T/N 80-0034."

[63] Cramer, S., & Covino, B. "ASM Handbook Volume 13C: Corrosion: Environments and Industries."

[64] Linzey, W. "Development of an Electrical Wire Interconnect System Risk Assessment Tool (DOT/FAA/AR-TN06/17)."

[65] National Transportation Safety Board. "Aircraft Accident Report: United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux Gateway Airport, Sioux City Iowa, July 19, 1989 (NTSB/AAR-90/06)."

[66] Voevodin, N., et. al. "Non-Chromated Coating Systems for Corrosion Protection of Aircraft Aluminum Alloys."

[67] United States Government Accountability Office. "Defense Management: DOD Needs to Monitor and Assess Corrective Actions Resulting from Its Corrosion Study of the F-35 Joint Strike Fighter."

the effects of thermal environment on the degradation of materials in the presence of aggressive chemistries. Ultraviolet light degradation can likewise be modeled using similar tools, but has not seen nearly the amount of study that other mechanisms have to date.

Examples of chronologically driven failure modes are:

- Stress corrosion cracking (SCC) is a pernicious form of corrosion in which the combination of a susceptible high strength alloy, sufficiently high operating stresses, and a corrosive environment act to cause intergranular cracking. This cracking can progress very quickly. The crack can be extended by SCC mechanisms as well as fatigue loading.[68]

- Corrosion exfoliation is a severe form of intergranular corrosion, in which layers of grains essentially delaminate. This form of corrosion is seen on aluminum alloys used for empennages and wing skins.[54]

- Ultraviolet and chemical exposure of polymeric materials, such as fuel tank sealants, can lead to material embrittlement through cross-linking of polymer chains.[69]

- Engine turbine blade hot corrosion is a form of sulfurization that aggressively attacks nickel-based superalloy materials within certain temperature ranges. The source of the sulfur is normally ingested dirt. This form of corrosion can be mitigated by suitable turbine blade coatings.[70]

It must be noted that while the mechanisms of usage and aging are independent, their effects are coupled. Aging can cause flaws to initiate early (sharp ones in the case of stress corrosion cracking, blunt ones in the case of exfoliation) and usage can drive their growth. Similarly, fatigue can initiate a flaw and an aggressive environment can accelerate its growth. Moreover, fatigue loading of a flaw in an aggressive environment produces flaw growth that is faster than happens in a laboratory air environment. In cases in which the stress intensity factor of the flaw is higher than the threshold for stress corrosion cracking, the crack growth rate is dependent on both the load cycle range and the amount of time at which the load is held. In these cases, the crack growth rate has both a stress and time dependence.

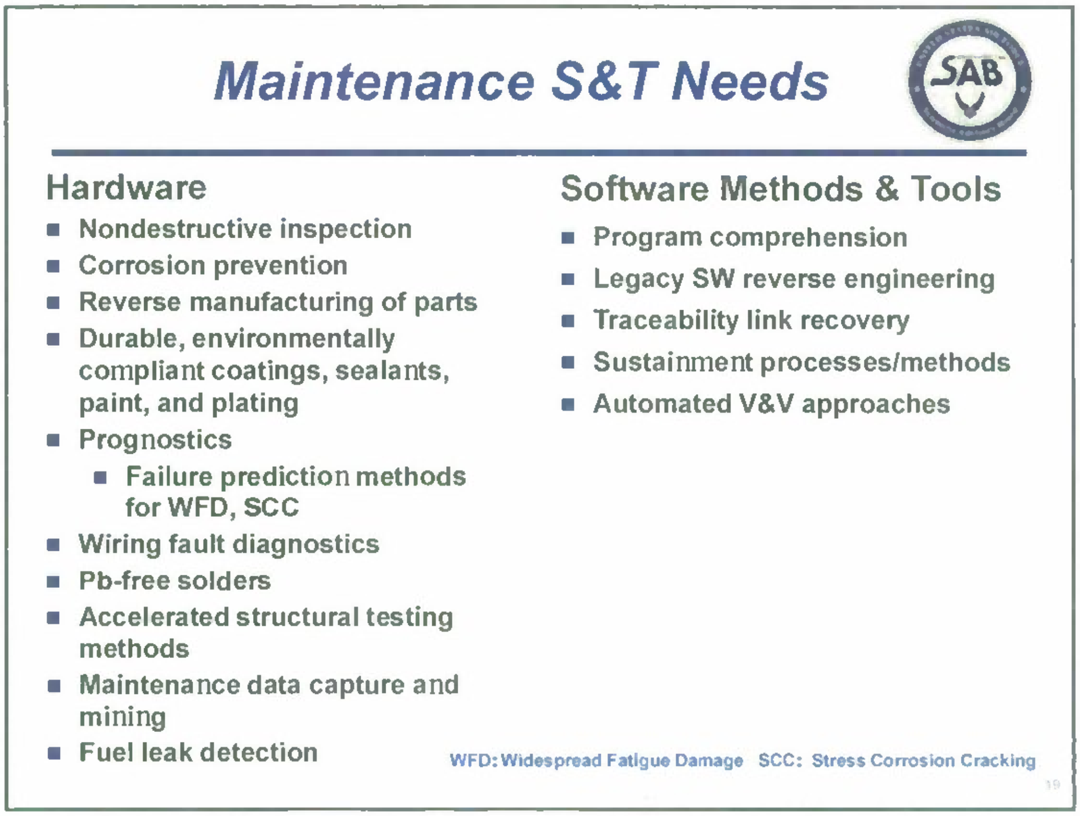
The practical consequence of the different types of aging is that predicting life of an MDS has a measure of uncertainty. Each aircraft within an MDS typically has specific usage and exposure to different environments depending on basing. In the long run, the advantage of prognosis is that through use of sensors and reasoners, the aging of each individual aircraft can be monitored. However, this requires sufficient fundamental understanding of the different aging mechanisms that their progression can be predicted from the data developed.

---

[68] Fontana, M. "Corrosion Engineering."

[69] National Research Council National Materials Advisory Board. "Research Opportunities in Corrosion Science and Engineering."

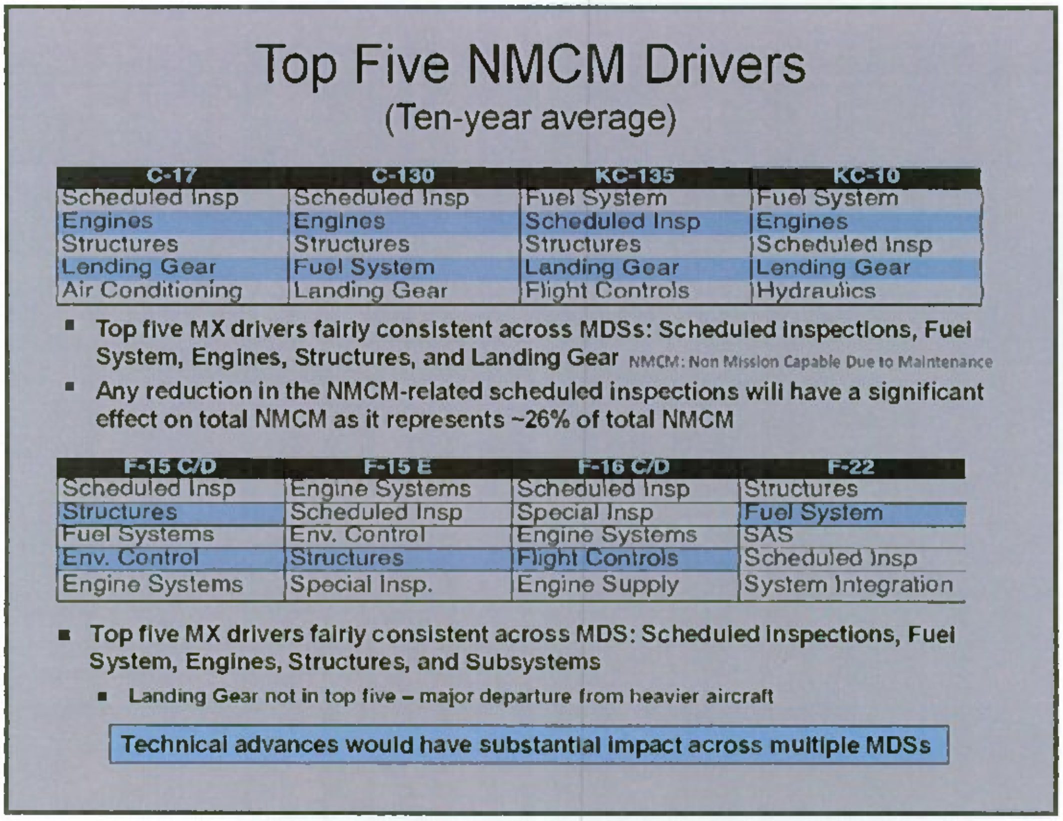
[70] Rapp, R. "Hot Corrosion of Materials."



The primary aircraft maintenance Science and Technology (S&T) needs for the Air Force involve both hardware and software. As noted in Figure 2-9 (below) the top four hardware needs shown on the above chart were consistently among the top five for every MDS reviewed: Nondestructive inspection; corrosion prevention; reverse manufacturing of parts; and durable, environmentally compliant coatings, sealants, paint, and plating. Inspections were a major time driver for depot maintenance and thus motivate the desire for not only nondestructive inspection techniques but non-invasive inspection techniques that do not require the aircraft to be dismantled to determine hidden defects and damage. The interest in corrosion is driven by the simple aging of the aircraft seen in the USAF fleet and by the use of non-chromate primers in the latest aircraft. The latter experience accelerated corrosion damage due to the reduced ability of these primers to protect the aluminum and the breakdown of the sealants used for these aircraft – thus the interest in primers, sealants, and coatings. Rapid processes for manufacturing obsolete parts are the key to reducing time in depot for aging aircraft. Note that of these top four needs, two are directly related to aging mechanisms and the other two handle both aging and usage based mechanisms.

The remaining technology needs are identified by more than one MDS but not as pervasively as the top four technologies. These are seen by the Study as being those that could provide the best benefit to the Air Force for future maintenance of aging aircraft. Prognostics are key to prediction of maintenance requirements when the aircraft comes into depot, one of the major contributors to time before work commences in the depot and might eventually reduce or eliminate the need for pre-induction inspection of the aircraft. Data mining capabilities would allow the Air Force to determine the configuration and previous maintenance activities

performed on that particular aircraft and reduce the amount of inspection that is required when entering the depot. Wiring faults and leak detection capabilities are crucial to determining hard to find sources of electrical and bladder faults. These faults often are found in locations or components that confound the source detection problem. Lead free solders with good conduction capabilities and fatigue lives have not yet been achieved but are needed to provide long life for electrical components while still offering an environmentally acceptable alternative to conventional solders.



Top Five NMCM Drivers

(Ten-year average)

C-17	C-130	KC-135	KC-10
Scheduled Insp	Scheduled Insp	Fuel System	Fuel System
Engines	Engines	Scheduled Insp	Engines
Structures	Structures	Structures	Scheduled Insp
Landing Gear	Fuel System	Landing Gear	Landing Gear
Air Conditioning	Landing Gear	Flight Controls	Hydraulics

- Top five MX drivers fairly consistent across MDSs: Scheduled Inspections, Fuel System, Engines, Structures, and Landing Gear NMCM: Non Mission Capable Due to Maintenance
- Any reduction in the NMCM-related scheduled inspections will have a significant effect on total NMCM as it represents ~26% of total NMCM

F-15 C/D	F-15 E	F-16 C/D	F-22
Scheduled Insp	Engine Systems	Scheduled Insp	Structures
Structures	Scheduled Insp	Special Insp	Fuel System
Fuel Systems	Env. Control	Engine Systems	SAS
Env. Control	Structures	Flight Controls	Scheduled Insp
Engine Systems	Special Insp.	Engine Supply	System Integration

- Top five MX drivers fairly consistent across MDS: Scheduled Inspections, Fuel System, Engines, Structures, and Subsystems
  - Landing Gear not in top five – major departure from heavier aircraft

Technical advances would have substantial impact across multiple MDSs

Figure 2-9. Top Five Not-Mission-Capable (Maintenance) Drivers.

Software needs are identified to aid in reducing the time required to determine faults in software, determine a viable and safe repair, and implement and validate the repair. The elements felt to best facilitate this effort include:

- Program comprehension,
- Legacy software reverse engineering,
- Traceability link recovery,
- Sustainment processes/methods, and
- Automated verification and validation (V&V) approaches.

Understanding the purpose of the software is crucial to ensuring that repairs are made that accomplish the same intent. Developing methods that allow reverse engineering of legacy software, such as intent determination, language upgrades, and capability modules can all help programmers reestablish conformance with legacy codes while upgrading the capability to maintain it in the future. Automated validation and verification methods obviously can help deliver software to the field that is robust and reliable and is especially crucial for flight critical software.

To further confirm the hardware needs of the MDSs reviewed by this Study, the tables shown in Figure 2-9 (above) show the top five needs for each of the MDSs for which "deep dive" reviews were performed.

The Air Force uses NMCM as a metric to classify field maintenance drivers. NMCM, when measured in hours, provides the time that an aircraft is unable to be scheduled for a mission due to maintenance. NMCM hours are tracked in calendar time from the moment when maintenance begins until the time the aircraft is released to the active schedule. For example, if an aircraft was out of service for three days due to engine maintenance, 72 hours would be recorded in the NMCM database. Note that the NMCM time for this example is 72 hours regardless of the time actually required to perform the engine maintenance.

Top 10 NMCM drivers were provided in various briefings for the following MDSs:

- Mobility: C-5, C-17, C-130, KC-135, and KC-10
- Fighters: A-10, F-15, F-16, F-22
- Bombers: B-1B
- Unmanned: MQ-1, MQ-9, RQ-4A
- Misc: E-3, E-4, E-8, U-2, HH-60, T-38

Detailed investigations of the mobility and fighter fleets were completed and are discussed below.

The NMCM data across the Mobility fleet were remarkably similar for each MDS. The top five drivers from Figure 2-9 above were nearly the same, although the order (one to five) was not always the same. These top NMCM drivers are:

- Scheduled Inspections
- Fuel Systems
- Engines
- Structures
- Landing Gear

Additional drivers in the top five for some MDSs were Flight Controls, Air Conditioning, and Hydraulics.

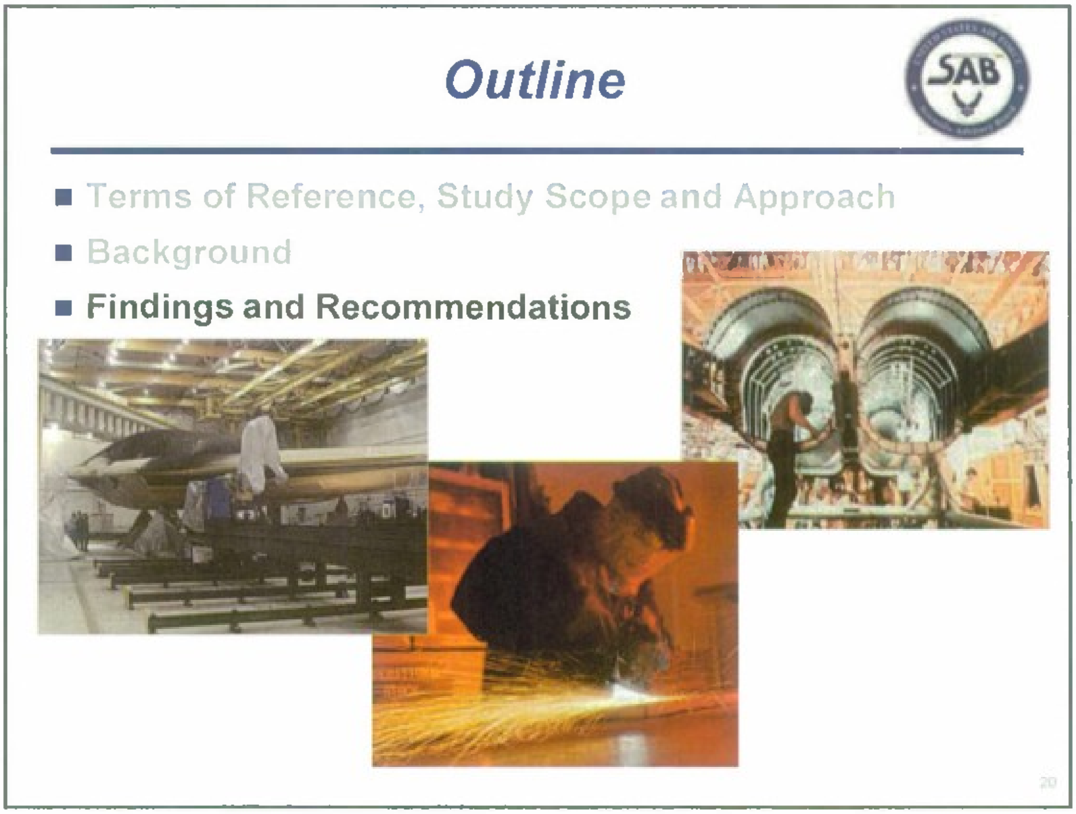
The fighter fleet NMCM results were not as consistent as the mobility fleet. The top drivers for the fighter fleet were (again not in order) were:

- Scheduled Inspections
- Fuel Systems
- Engines
- Structures
- Subsystems

A finding from this Study is that the top NMCM drivers are similar across all USAF Mobility and Fighter MDSs. Landing Gear is more significant in the Mobility Fleet, and Subsystems is higher in the Fighter Fleet.

The consistency of the NMCM drivers provides the Air Force an opportunity to utilize S&T and other methods to improve the availability across various fleets. For example, improved RCM or MSG-3 analyses could be used to reduce scheduled inspections. Further, S&T improvements in structural inspection or corrosion protection would impact multiple fleets. This wide benefit will help justify the investment in S&T for these areas.

Section 3: Findings and Recommendations



The Findings and Recommendations of this Study are focused in six areas:

- Improved efficiency metrics,
- Improved supply chain efficiency,
- Increasing software sustainment needs,
- Science and technology needs,
- Adopting commercial aircraft maintenance practices where applicable, and
- Strengthening the integrity programs to ensure continued airworthiness for the aging USAF fleet.

The Study finds that the aircraft availability metrics used by the USAF to measure the performance of depots do not necessarily drive maintenance to efficient sustainment processes. The Study recommends that ALCs adopt an efficiency metric based on the cost of aircraft availability and use available data to characterize the cost of aircraft availability as a function of

depot flow rate. This insight can be employed to determine the efficacy of initiatives that drive toward more efficient use of labor and facilities at each ALC.

The Study finds that supply chain management leads to inefficiencies because it cannot effectively forecast the parts and component needs accurately. Part of this problem is the large number of independent databases used by USAF in tracking its aircraft, their configurations, their maintenance actions, and the parts used for maintenance. The Study recommends that AFMC develop overarching software database structures that allow read and search capability for all the databases used by each of their MDSs. The Study believes that this will allow USAF to remove redundancy in their databases, provide better cataloguing of the parts and components they order (or should order), and, thus, have a more accurate assessment of the needs for their MDSs.

The Study finds that every aircraft in the USAF fleet is becoming more dependent on software to provide flight and mission functionality. Software is more integrated into new aircraft like the F-22 and F-35, but it is even becoming a larger player in legacy aircraft through upgrades like the Active Electronically Scanned Array (AESA) radar for the F-15, which has more lines of software than the F-22. The Study recommends that the ALCs develop enduring relationships with the OEM software developers to ensure cradle to grave software sustainment capability throughout the lifetime of each MDS. It also recommends that the CSSIP Program be given an accelerated timeline in which to develop standards and verification and validation processes for software that will enable flight safety related software to be independently qualified for flight operations. This will be crucial to future airworthiness qualification for aircraft currently in development as well as replacement components driven by software in legacy platforms.

The Study finds that AFRL needs to rebalance their investment portfolio to increase the funding available for aircraft maintenance related technologies. Currently AFRL sustainment R&D funding is largely focused on future materials and applications. But the Study recommends that AFRL and AF Office of Scientific Research (AFOSR) sustainment funding be refocused on materials and maintenance technologies associated with aging aircraft because the number of those MDSs far exceeds those MDSs in development. AFOSR should fund work in determining lives for aging causes (rather than usage causes) including corrosion assisted fatigue, stress corrosion cracking and chemical degradation of sealants. Non destructive inspection (NDI) should also be considered for increased activities for aging related failure modes (for example: corrosion, ultraviolet exposure degradation, and moisture degradation). AFRL should partner with the MAJCOMs on transitioning technology from TRL 6 and MRL 6 using full scale demonstrations to TRL 9 and MRL 9 in order to facilitate adoption by the ALCs.

The Study finds that there are a number of practices used by commercial airlines in their maintenance and depot activities that might provide efficiencies and capabilities that could reduce maintenance costs for the USAF. These include greater emphasis on RCM and incorporation of MSG-3 practices. Therefore, the Study recommends that the Air Force compare these practices with the current USAF practices and determine which of these practices provide cost and time reductions and which do not—adopting those that provide greatest benefit.

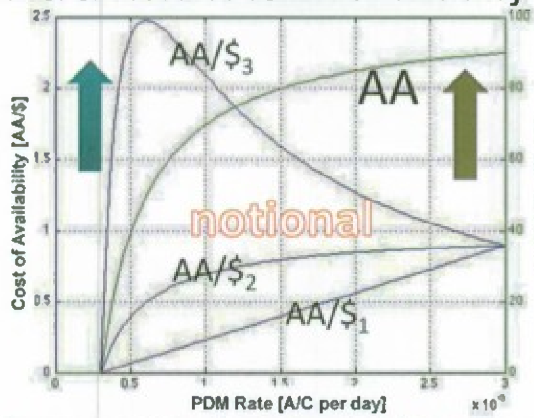
The Study finds that the Integrity Programs are crucial to continued airworthiness of the USAF fleet of aircraft. While the Aircraft Structural Integrity and Propulsion Systems Integrity Programs are mature and functioning well, the remaining integrity programs need work to

elevate their capabilities to the same level of rigor of these mature programs. The Mechanical Systems Integrity Program is just being reinvigorated and has held its first conference to share best practices and preferred processes among the technical community and its proposed Military Standards revisions to ensure system integrity. Similarly, the Avionics Integrity Program is just being reinstituted and is still seeking the processes and organization that will make it as valuable and productive as an ASIP or PSIP program. And as mentioned before, it is crucial to accelerate the formation and institution of the Computer Systems and Software Integrity Program to provide consistent and valid verification of software, especially for flight safety critical components.

Actions are recommended for each of these findings in the subsequent sections of the report.

Finding 1
Depot Efficiency Not Quantified

- **Sustainment investments are driven by aircraft availability set by MAJCOMs, which may not correlate to resource utilization efficiency**
  - **Cost of Aircraft Availability [AA/$] is a measure of depot efficiency, i.e., output ÷ input**
  - **Measures to increase depot flow such as High Velocity MX (HVM), extra shifts, overtime, etc., may be inefficient, e.g., flooring the gas pedal analogy**



- **A quantitative understanding of how to best use resources is lacking**

The "opportunity cost" of sustainment investments is not understood

21

The Study Panel has found that the fundamental metric used to guide sustainment investment is the required aircraft availability for each MDS, which is defined by the MAJCOMs. In an era of constrained budgets, such a metric ignores the cost required to achieve the requisite AA. As a result, it is not evident whether the required AA is achievable within the budget bounds, nor does it provide guidance toward cost-efficient processes and practices. In essence, it is not clear that the required AA is anywhere near the AA that can be achieved with the highest resource utilization efficiency.

In defining a metric to capture the efficiency of achieving aircraft availability, it is recognized that there are at least two types of efficiency. The first type of efficiency is associated with the productivity of the workforce. The AA improvement programs strive to make the maintainer, in the field and at the depot, more efficient in their activities by defining standard work packages, knowing the condition of the aircraft in advance, positioning needed tools for easy access, and fixturing the workspace for ergometric access, to name a few techniques. The goal is to increase AA, while keeping costs fixed, by increasing the productivity of the workforce per labor hour (or dollar) spent. However, by assuming that cost is fixed, there is only limited insight into the broader relationship between AA and cost.

The second type of efficiency is associated with the marginal cost of availability. It may be true that the marginal cost of the last 5% of aircraft availability (i.e., the cost of raising AA from 75% to 80%) is much higher than the previous 5% (i.e., the cost of raising AA from 70% to 75%). This increase in marginal cost at higher AA can arise from several sources. For example, extra workforce shifts overnight or on the weekends can incur higher wages for the same

workforce productivity. Furthermore, increasing inventory, to reduce NMCS and thereby improve AA, can incur higher costs due to unused stockpiles. If one tracks a metric such as aircraft availability divided by cost (AA/$), one can better understand these marginal costs. The result might reveal that relaxing AA requirements a little may free up substantial resources that could be used more effectively elsewhere.

To better illustrate the relationship between the metrics of AA and AA/$, as well as the roles of AA improvement and initiatives such as HVM and lean practices, a notional model is shown in the figure below.

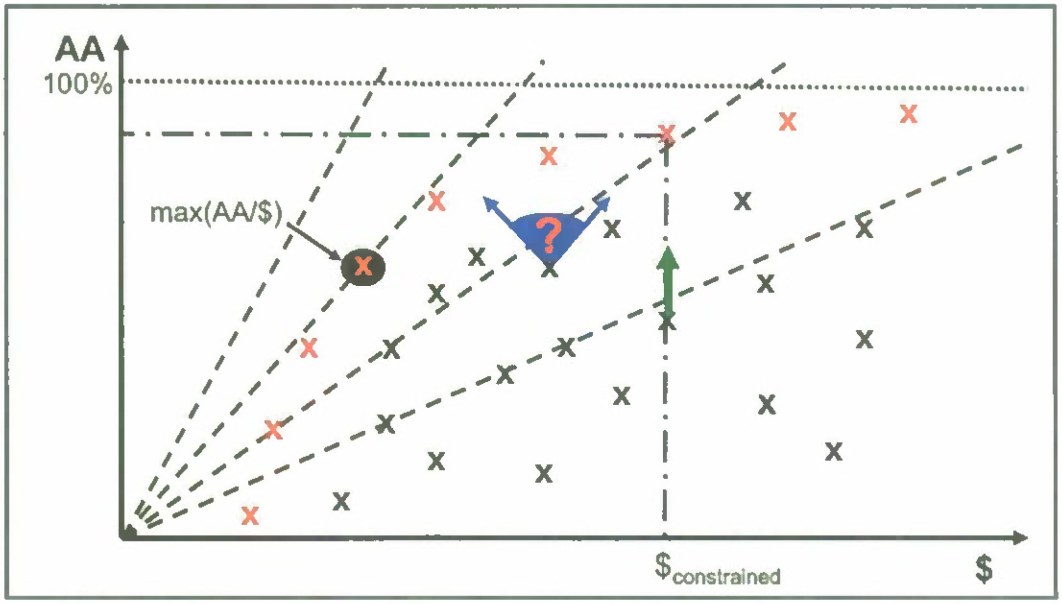


Figure 3-1. Aircraft Availability versus Cost for a Notional MDS. Note: The points denoted by a red X correspond to process-cost efficiency points.

This figure plots aircraft availability versus cost for a notional MDS. The theoretical limit on availability is 100% and is shown by the horizontal dotted line. Each 'X' in the plot represents a unique process for sustaining that MDS. Some provide low availability at high cost (lower right) and are clearly inefficient since other processes provide both higher AA and lower cost (upper left). The red 'Xs' correspond to those processes that are most efficient at each cost point. In other words, in order to increase AA for sustainment process represented by a red 'X' requires an increase in cost. Correspondingly, to reduce cost requires a reduction in AA. The 'X' processes at each cost point comprise the Pareto-optimal front that corresponds to the most efficient processes for productivity, or productivity efficiency.

Several other features can be seen in this figure. It is reasonable to assume that the Pareto-optimal front is roughly shaped as shown because the MDS must asymptotically approach 100% AA as cost is increased (right side) and there are significant facility charges before the first maintainer is hired (left side). The vertical green arrow indicates the effect of improving productivity efficiency under constrained cost. The blue region with the red question mark (?) indicates the range of possible effects caused by HVM. While clearly improving AA, it is unclear whether HVM does so at increased or decreased cost. For example, the infrastructure

that is put in place to improve the productivity of the maintainer through standard work planning, kitting, etc. may save or incur higher costs.

The second type of efficiency, the cost of availability is also shown in the above figure. The dashed lines show radial spokes of constant AA/$. The spoke with the highest AA/$ that intersects the Pareto optimal front identifies the process that maximizes AA/$ (i.e., the 'X' with the black dot behind it). To increase or decrease AA from this process incurs a reduction in the AA/$ metric by increasing marginal cost or reducing amortization of facility costs, the marginal cost efficiency. The process labeled as 'max (AA/$)' is at the "sweet spot" on the Pareto-optimal front. Therefore, improving productivity efficiency through availability improvement programs moves the sustainment towards the Pareto-optimal front and marginal cost efficiency reveals the most efficient process on that front.

To illustrate the differences that the AA and AA/$ metrics can provide, a notional example is shown that relates these metrics to the PDM rate. In this example, PDM rate is defined as aircraft (A/C) per unit time. Assume that the rate that A/C depart the depot after maintenance ($\dot{D}$) matches induction rate ($\dot{I}$) by making the number of A/C in docks (n) inverse to the PDM rate ($\dot{P}$). That is,

(1) $$\dot{D} = n\dot{P} = \dot{I}$$

where

(2) $$n = \dot{I}/\dot{P}$$

A simplified definition of availability equals fleet size (F) minus number of A/C in docks normalized by fleet size and multiplied by 100%:

(3) $$AA = (F - n)/F \times 100\%$$

Cost ($) is proportional to the number of A/C in docks times PDM rate raised to an exponent (e):

(4) $$\$ \sim n\dot{P}^{e}$$

Three cost models are assumed:

- Cost is independent of PDM rate (e = 0),
- Cost is proportional to PDM rate (e = 1), and
- Cost grows faster than PDM rate (e > 1).

The notional figure in the Finding chart above shows four curves. The aircraft availability curve (labeled AA and corresponding to the right hand vertical axis) starts at AA = 0

when the PDM rate causes the number of aircraft in depot to equal the fleet size and asymptotes to 100% at high PDM rates, when there are no aircraft for that MDS in depot. In addition to this curve, there are three curves that are based on the three separate assumptions concerning the costs incurred while performing depot maintenance and upgrades.

- The first of these curves assumes that cost is independent of PDM rate (e = 0), then efficiency (AA/$\$_1$) increases linearly with PDM rate and is a maximum when AA is a maximum. This is an unlikely scenario since it is reasonable to assume that increasing PDM rate increases cost unless cost is dominated by poor productivity efficiency.

- The second curve assumes that cost increases linearly with PDM rate (e = 1), and efficiency (AA/$\$_2$) is once again a maximum when AA is a maximum. However, there is a diminishing improvement in efficiency at higher PDM rates. This scenario is more plausible because more maintainers and support personnel working on a plane could move an aircraft through PDM faster. However, at high PDM rates, cost elements such as overtime will likely cause cost to increase faster than the PDM rate.

- The third curve assumes that cost increases faster than PDM rate (e > 1), due to factors such as overtime and substantial increase in support personnel. For this assumption, efficiency (AA/$\$_3$) is a maximum for a PDM rate that is substantially different than for AA. Under any of these scenarios, it would be useful to know the PDM rate that maximizes the cost of availability metric (AA/$) as well as the highest AA that is affordable so that decision makers can balance efficiency and availability subject to cost constraints.

As an analogy, consider a car race. The winner will be the driver that can maintain the highest average speed during the race. However, with a limited capacity fuel tank, fuel efficiency becomes an additional important metric that can help the driver avoid a time-consuming fuel stop. Flooring the gas pedal in the car maximizes instantaneous speed (e.g., performance [AA]) but does not maximize miles per gallon (e.g., efficiency [AA/$]). Finding the proper balance between fuel efficiency and performance, while being able to shift between the two, allows the driver to win the race. Finding this proper balance requires the driver to know the performance of the vehicle across the car's range of speeds.

If the Air Force can quantify the availability (AA) and the cost efficiency (AA/$) of each MDS that can be achieved for different levels of investment, decision makers could make informed sustainment investment trades across the enterprise.

In summary, the Panel finds that the metric of aircraft availability only captures part of what is important to the sustainment enterprise in a cost-constrained environment. A metric such as AA/$, which is not currently being tracked by AFMC or Air Mobility Command, complements AA by providing an efficiency metric. Such a metric can reveal how efficient utilization of resources can best be achieved. Since AA may have high marginal cost, there is an opportunity to explore how lowering AA for some MDSs, to sustain closer to maximum (AA/$), might free resources that could be better used for other MDSs.

Recommendation 1
Quantify Depot Efficiency

- Use existing USAF data to quantify and model the cost of availability (AA/$) as an efficiency metric and employ it, along with AA, to inform sustainment investment decisions for each MDS [OPR: AFMC/A4]
  - Quantify AA/$ as a function of PDM rate over a broad range of costs to identify the "sweet spot" in efficiency
    - If AA/$ decreases as the desired AA is approached, the availability of those additional A/C is incurring higher marginal costs
  - Employ the model to analyze the efficacy of various sustainment initiatives being proposed to improve depot flow and efficiency

Allows decision makers to analyze proposed PDM initiatives from both an availability and efficiency perspective

PDM: Programmed Depot Maintenance

22

The Study Panel recommends that the Air Force mine existing USAF data, combined with economic models, to quantify the cost of availability (AA/$) as an efficiency metric. This metric should then be used, along with availability (AA), to make sustainment investment decisions for the various MDSs in the enterprise. The Panel recommends that this be done initially for PDM but can be eventually broadened to include all elements within the sustainment enterprise. The Panel recommends three steps: quantification, integration, and analysis.

In the quantification step, the USAF needs to develop models that capture the relationships between aircraft availability (AA) and efficiency (AA/$) as a function of cost for each of the sustainment elements that drive these metrics. These include PDM performance, modification programs, field level maintenance performance, reliability and maintenance, supply chain performance, etc. This could be done incrementally. Initially, one model should capture AA and AA/$ versus PDM rate (first sub-step) as well as PDM rate versus cost (second sub-step). Once this model is assembled, it can be employed by decision makers to assess the efficacy of various PDM efficiency initiatives that are proposed.

Subsequently, this process can be repeated to capture other sustainment functions. For example, another model would capture AA and AA/$ versus NMCS as well as NMCS versus cost as a field level maintenance efficiency metric. Additional models should capture relationships for NMCM, etc. It is recognized that these models cannot be purely based upon empirical data. It is suggested that parametric models be developed based upon cost estimating relationships, performance models extracted from experiences with the HVM and lean programs,

as well as cost and performance data. The integration of parametric models with data permits broad parametric extrapolation anchored by data as well as expert opinion.

In the integration step, the individual AA and AA/$ parametric models, associated with each sustainment driver, are integrated to yield an MDS-level parametric model of the cost of availability. Parametric sensitivity trades can then be performed to identify couplings between sustainment drivers with respect to their impact on AA and AA/$. Pareto analysis and optimization can be conducted to balance investment across the various sustainment drivers to identify the sustainment investment strategies for each MDS as a function of different weightings between availability and efficiency.

In the analysis step, the integrated models for each MDS can be combined to optimize sustainment investments across MDSs. For example, slightly relaxing AA requirements on an MDS that has high marginal cost of availability, might free sufficient funds to substantially improve AA for another MDS whose improved AA could reap greater enterprise-wide capability. This ability to analyze sustainment return on investment across the USAF aircraft inventory could help decision makers to balance availability and efficiency during lean economic times. The Panel recognizes that AA goals are set by the Lead Major Commands in response to the mission needs of the Combatant Commands. Hence, it may not be possible to alter AA targets on the basis of marginal cost analysis. Nevertheless, these analyses would provide additional information for decision makers in the likely constrained cost environments the Nation faces where trades may well have to be made with inclusion of budgetary considerations.

Finding 2
Supply Chain Challenges

- **DMS becomes an increasing sustainment issue as aircraft age and OEM involvement is reduced**
  - **OEMs actively manage the supply chain early in service life**
  - **Original parts often unavailable, even during A/C design service life**
  - **Avionics replacements particularly challenging due to technology advances**
- **Inaccurate demand forecasting and lagging supply chain metrics result in inadequate supply support from both AFGLSC and DLA**
  - **Includes DLRs, consumables**
  - **Inaccurate, insufficient and inconsistent databases**
- **Increasing use of COTS parts engenders more rapid obsolescence due to short commercial product lifecycles**
  - **COTS parts discontinued much faster due to commercial drivers**
  - **Requires active management and planned refresh cycles**

Parts supply is an ever increasing issue as aircraft age

COTS: Commercial Off the Shelf DLR: Depot Level Repairable OEM: Original Equipment Manufacturer

23

Maintaining a robust supply chain requires knowledgeable sustainment engineers, accurate parts demand forecasting, and a viable base of suppliers. For new MDSs, the aforementioned supply chain requirements are handled by the OEMs. However, supply chain management often shifts to the Air Force especially as the life of an aircraft type is extended beyond its original service life and OEM involvement in O&M is reduced as a result of a shift towards organic sustainment. This shift drives several requirements for the Air Force.

First, there is a need for increasing numbers, and experience, of sustainment engineers at the ALCs and Item Managers within the supply chain enterprise (i.e., AFGLSC and DLA). Sustainment engineers are instrumental in developing the PDM work tasks and bill of materials. They have technical authority for analyzing alternative part and subsystem solutions as original parts encounter DMS issues. They must consider airworthiness, maintainability, and system reliability. Often dependencies between parts or subsystems are not sufficiently documented in the Technical Order and are only understood through experience. Similarly, Item Managers within AFGLSC and DLA must maintain a viable parts listing and supplier base. In doing this, they too must address DMS and obsolescence issues with knowledge of the impact on MDS maintainability.

Second, timely and accurate parts demand forecasting is needed to minimize aircraft down time (i.e., Mission Impaired Capability Awaiting Parts (MICAP), NMCS) resulting from parts delivery unavailability. Forecasting is the responsibility of AFGLSC and DLA with AFGLSC pulling supply requirements from the field and depots. AFGLSC maintains a database of historical parts usage that is the basis for forecasting future needs over a five year time

horizon. AFGLSC's supply chain forecast accuracy for FY09 was less than 50%.[71] An additional supply complication is that the final parts procurement is split between AFGLSC and DLA, with the line of responsibility not always clearly defined, thereby resulting in supply chain execution failures. It should also be noted that this inability to forecast needs accurately cannot be attributed solely to the sustainment engineers or the supply chain managers. This Study found that forecasting errors can arise from data supplied from the depots and from the field being either inaccurate, or more likely, recorded at too high a level to accurately reflect the parts used to make repairs. Other cases were found in which replacement parts were remanufactured in depots and never turned in for replacement. When this happens it distorts the real need for obsolescent parts.

Finally, the Air Force needs to proactively manage DMSMS issues. This is a growing issue as the use of COTS parts has increased and COTS product lifecycles have decreased because of increased capacity of computer chip based functionality that follows "Moore's Law" and the ever shortening obsolescence lifecycle of commercial products.

Database Complexity

During the Panel's visits to each of the three USAF ALCs, each MDS SPO was requested to present to the Study Panel the databases currently in use for the respective MDS. The total summary list of databases reported is shown in Table 3-1 below. Many of these cannot be managed using modern database tools. In addition, in many of the databases, the original entry of maintenance action documentation varies widely in specificity. For example, the detail level of the WUC identified for the maintenance action taken varies from accurate and detailed descriptions to the highest possible level of code for the activity. For example, the same maintenance action for different field activities may be identified to the 3-digit or 5-digit WUC level for different locations on the same MDS. The 5-digit code may call out a specific action, but the 3-digit code may only describe the component being acted upon and not the action being performed. As a reflection of the magnitude of field data discrepancies, C-17 sustainment is provided under Contractor Logistics Support, and under this contract, as noted earlier, Boeing "cleans" over 40,000 C-17 maintenance records per month using cross referenced part data to infer the specific action taken on any particular field or depot action record.

In order to fully understand the Maintenance Actions (Field and Depot) taken on a particular aircraft throughout its lifetime, an Integrated Maintenance Data System would be required to corroborate the data relevant to that aircraft contained in all of these databases. An Integrated Maintenance Data System would require a substantial initial effort for collecting and "cleaning" data across all organically sustained MDSs. Going forward, standardization of Maintenance Action reporting in the field is mandatory.

---

[71] Air Force Global Logistics Support Center. "Demand Forecast Accuracy."

Database	Title	Database	Title
Depot 202s	Depot Request for Assistance	G081	Maintenance Information System
Field Level 107s	Field Request for Assistance	CEMS	Comprehensive Engine Management System - Fed by REMIS, CAMS, or GO81
339s	DLA Request for Engineering Support	IMDS	Integrated Maintenance Data System
ETIMS/ IDM/ JCALS	Technical Orders	D200RMS	AFGLSC Forecasting
JEDMICS	Drawings *(Joint Engineering Data Management Information and Control System)*	AFTOC	Total MDS Costs
AVCOM	Parts Obsolescence *(Advanced Component Obsolescence Management)*	LIMS-EV	Availability, Utilization, Maintenance (Logistics Installations and Mission Support - Enterprise View)
JDRS	Deficiency Reports *(Joint Deficiency Reporting System)*	ESS	MICAP and High Priority Orders
AFSAS	Mishap Database *(Air Force Safety Automated System)*	ASIMIS	Aircraft Structural Integrity Management Information System
CAMS	Field Maintenance *(Core Automated Maintenance Systems)*	MNCL	Master Nuclear Certification List
REMIS	Maintenance *(Reliability and Maintenance Information Systems)*	F-16	
PDMSS	Depot Maintenance *(Program Depot Maintenance Support System)*	IMIS	Integrated Maintenance Information System
JRAMS	Joint Readiness Automated Management System	DESTRAP	Damage Evaluation System Technical / Repair Assistance Page
CAFDEX	O&M Budget Requirements, PDM Work spec	CIRE	Common Inspection Reporting Engine
WSMS	Sustaining Engineering and Tech Order Budget	IAT	Individual Aircraft Tracking (IAT) (Drives Inspections, captures results)
SRA	Software Maintenance Budget	CAPS	Component Analysis and Prioritization System
G004L	Temporary Work Requests (Organic Software, Tear Downs, Depot Field Teams)	FIN	Field Information Network

Table 3-1. Various DoD Sustainment Databases used by AF Materiel Command System Program Offices.

Recommendation 2
Improve Supply Chain Forecasting

- Improve AFGLSC supply chain forecasting to minimize field level maintenance and depot production delays due to parts shortages [OPR: AFMC/AFGLSC]
  - Implement an analytically-based parts forecasting system utilizing part tracking, field history, and reliability data
  - Provide robust engineering support within the Program Offices and AFGLSC to permit technically sound sourcing decisions and Manufacturing Review Board (MRB) activities
  - Develop supply chain metrics that tie to AA/$, not parts delivery
  - Promulgate the use of COTS obsolescence forecasting tools (e.g., AVCOM) early in the maintenance planning cycle for all MDSs

Accurate parts forecasting is a key enabler for increased AA

AVCOM: Advanced Component Obsolescence Management

24

Although the Air Force is making progress in improving its supply chain forecasting, further improvements are needed to meet the Air Force's objectives for minimizing delays in field level maintenance and depot production. To achieve the overarching recommendation, four actions are suggested.

First there is a need to improve parts tracking, field history, and reliability data. Today there is no automated, or consistent, enterprise approach to capturing these data and feeding it into the D200A forecasting system. Tying parts data to tail number and flight history will be important for enabling more sophisticated forecasting. While some statistical analysis currently exists in the D200A toolset, more sophisticated data analysis based on predictive analytics warrants investigation once the database is improved. Predictive analytics is a growing field based on the use of computer-generated models of large datasets that can be used to project future outcomes, or in this case, forecast future parts needs. Predictive analytics has found application in fields such as actuarial science, financial services, insurance, telecommunications, retail, travel, healthcare, and pharmaceuticals. Once the parts database includes sufficient, and validated, reference information such that representative models can be developed, predictive analytics should significantly improve parts forecasting.

Second, the ALCs need to have sufficient sustaining engineering staff in both numbers and experience to perform parts determinations. This is particularly true when DMSMS issues require new parts to be identified and airworthiness needs to be recertified. AFGLSC and DLA also need experienced Item Managers to maintain a robust parts list and supplier base.

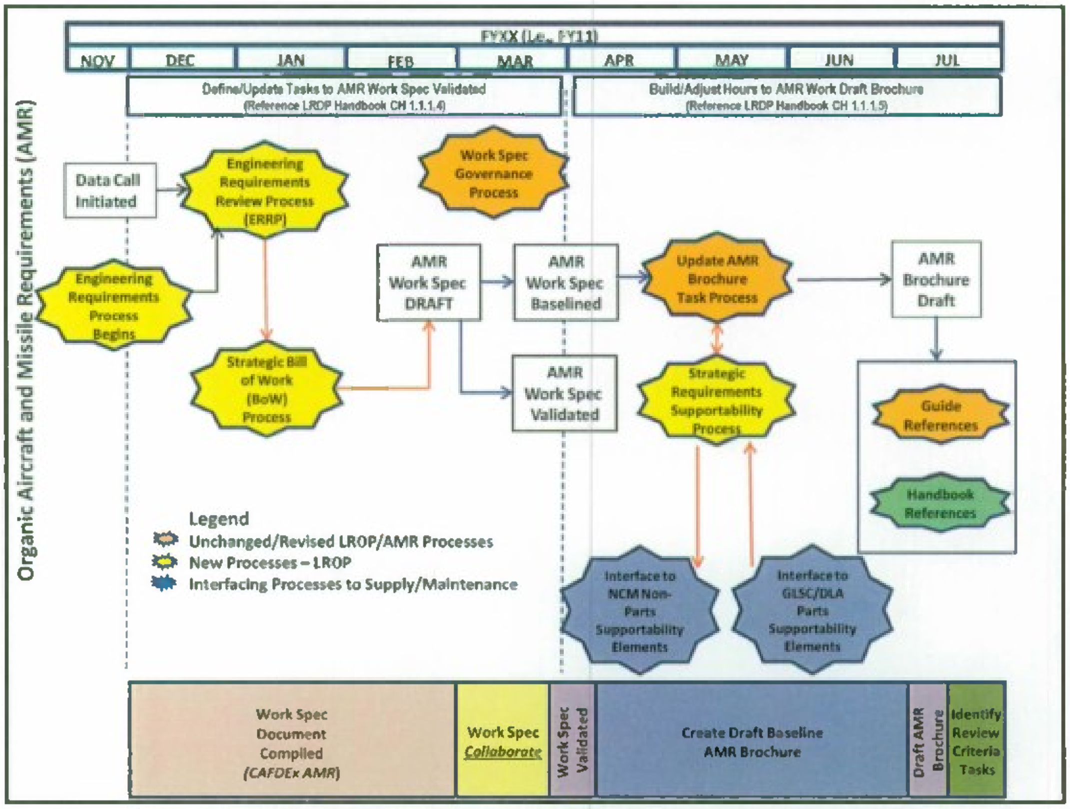


Figure 3-2. Air and Missile Requirements (AMR) Logistics Requirements Determination Process.

Supporting the first and second recommendations:

- Supply chain requirements are developed under the annual AMR Logistics Requirements Determination Process (LRDP) shown in Figure 3-2 above.[72]
- Initial PDM work task definition is done through the ERRP.
- ERRP output flows to the AMR work spec and then the AMR brochure. The AMR brochure documents the requirements to AFGLSC and DLA. These AMR requirements are used to forecast the parts requirements for the following five years.
- Demand Forecast Accuracy in recent years has been as low as 19%. AFGLSC has a plan to improve Demand Forecast Accuracy to 70% by end of FY15.

With the end result of the process being as low as 19%, it is obvious improvements must be made in forecasting tools/databases and in the staffing of requirements generation to improve overall supply chain execution.

[72] Lyman, S. "CAM LRDP Requirements."

Third, AFGLSC currently does not have metrics directly tied to AA, but only total parts delivery and cost. This can result in AFGLSC not delivering critical parts and maintaining the appropriate areas of working partnership with the ALCs that result in the lack of critical parts that can stop depot production.

Fourth, although the Air Force has developed the AVCOM software tool to analyze and predict parts obsolescence, AVCOM is not uniformly implemented. Furthermore, there would be additional benefits in using other commercial parts forecasting tools and insuring that the analysis process is made standard practice enterprise wide. Specifically, parts obsolescence and DMSMS analysis should be implemented as early in the supply chain planning process as possible, and made standard practice for all MDSs, to enable the identification of proactive solutions and not left until the back end when orders are being placed.

Finally, formally including RCM in the supply chain procurement process would improve forecasting, increase system lifetime, and thereby improve aircraft availability. RCM uses a combination of reliability data from the certification process along with a history of aircraft usage to determine the wear-out rate for each component of the aircraft. This forecasting capability could be a crucial component in parts forecasting for aging Air Force aircraft.

Finding 3
Increasing SW Sustainment Load

- **Software use/complexity and rapid technology refresh have grown faster than the USAF's ability to address it across the lifecycle**
  - **Moore's Law, commercial development, expanded threat spectrum, DMS-driven software interfaces, etc.**
- **USAF software sustainment efforts are growing**
  - **ALCs and CLSs spend considerable time/effort on both maintenance *and* upgrades of legacy software**
- **Software sustainment doesn't scale with number of aircraft, but with number of MDSs/variants**
  - **As fleet size decreases, software sustainment costs do not**
- **Lack of enterprise-level USAF strategy for software complicates sustainment over lifecycle**
  - **Transition from OEMs to ALCs often not seamless, predictable, or cost effective**

CLS: Contractor Logistics Support

Software sustainment is expected to grow significantly over time

25

Software has become strategically important for the DoD and USAF since its flexibility and fungibility enable it to scale in an unfettered manner that is different from hardware.[73] For example, unlike aircraft structures, sensors, and other hardware, software avionics upgrades can be delivered electronically and remotely, which enables quicker reaction to changes in threats, mission priorities, technology evolutions, and other operating environment characteristics. The principal challenge to successful software sustainment in the USAF is the ability of software engineers and managers to understand the purpose and complexities of original software codes so they can modify and improve it correctly, safely, dependably, rapidly, and cost effectively. The discussion below motivates our finding that software sustainment workload in the USAF is growing significantly over time.

Multiple trends are shaping the strategic importance of software for the USAF, including rapid technology refresh driven by Moore's Law, the increasing prevalence of commercial software practices, the expanded threat spectrum, DMS-driven interfaces, and the shift from analog to digital systems technologies. The confluence of these trends has caused the use and complexity of software in USAF weapons systems and their associated information technology

[73] National Research Council. "Critical Code: Software Producibility for Defense." *Note: These themes of the pivotal role of software in the DoD and USAF are specifically discussed in Chapter 1 of this report.*

(IT) ecosystems to grow significantly over the past six decades. These trends, in turn, have increased the software sustainment workload and cost drivers for the USAF.

As an example of the growth in use and complexity of software in the USAF, the following diagram shows the significant increase in source lines of code (a common measure of complexity) for operational flight programs (OFPs) in USAF fighter/attack airplanes from the mid-1950s to 2009.[74]

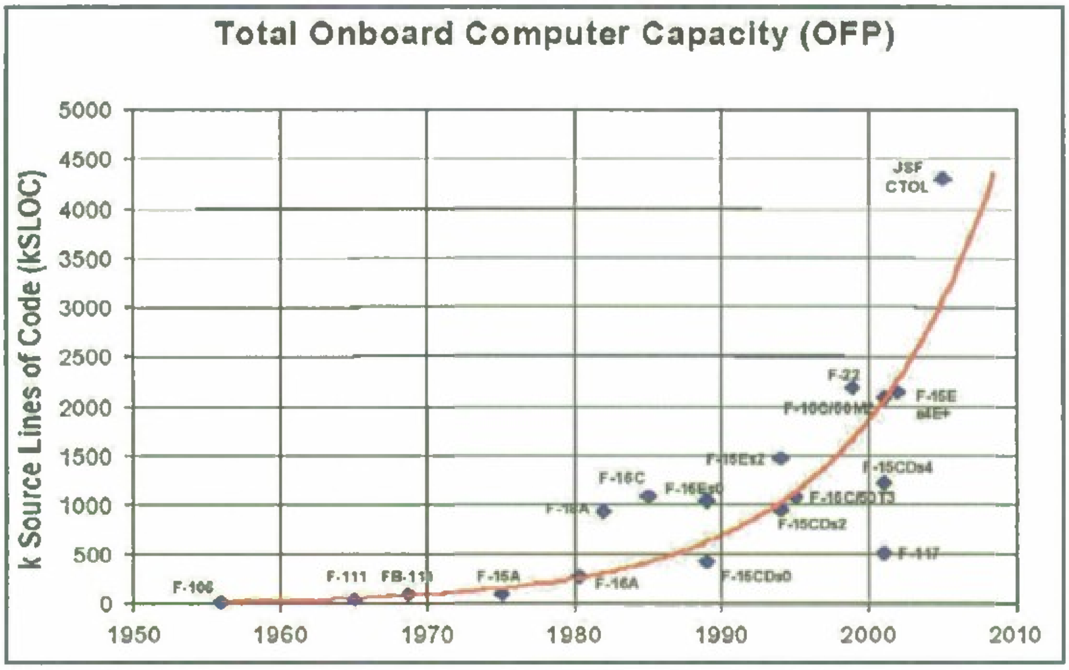


Figure 3-3. Historical Increase in Source Lines of Code (SLOC) for USAF Fighter Aircraft Operational Flight Programs.

Likewise, Figure 3-4 below shows an example of the increased reliance of USAF system functionality on software, as measured by the percentage of specification requirements involving software control, which has risen from approximately 8 percent of the F-4 in 1960, to 45 percent of the F-16 in 1982, to 80 percent of the F-22 in 2000.[75] The equivalent percentage for the F-35 will be at least 90%.

---

[74] Van Oss, D. "Avionics Acquisition, Production, and Sustainment: Lessons Learned -- The Hard Way." (Note: Van Oss Diagram obtained from and cited within: Dion-Schwartz, C., & Turner, R. "Software-Intensive Systems Producibility Initiative.")

[75] Defense Science Board. "Report of the Defense Science Board Task Force on Defense Software."

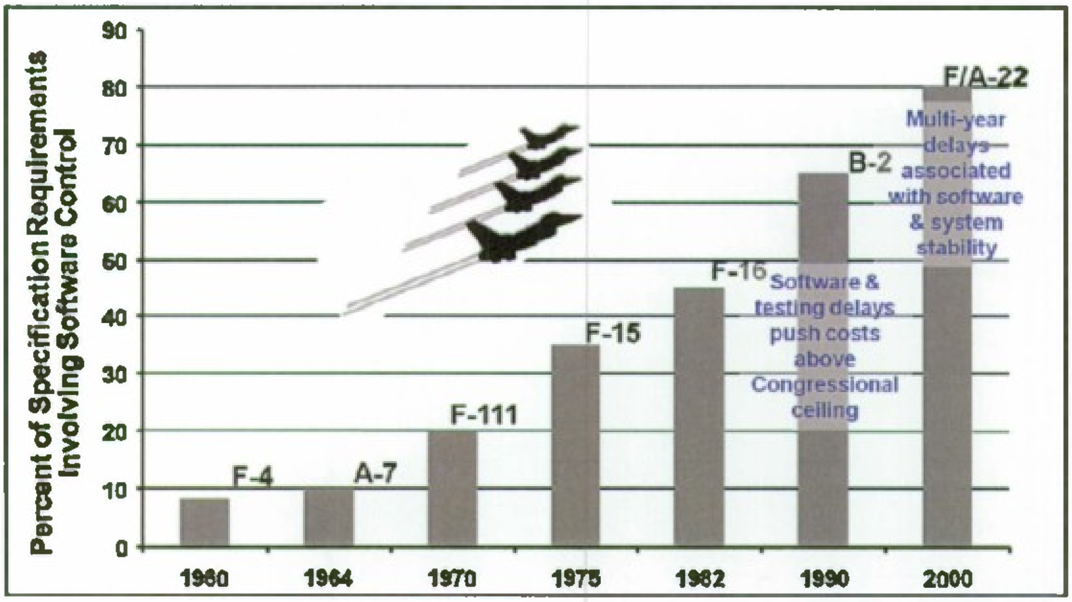


Figure 3-4. Examples of the Increased Reliance of USAF Aircraft Weapon System Functionality on Software. Note that in more recent systems software has been responsible for extended delays in the acquisition cycle.

Despite software's penchant to enable greater capability and flexibility, however, Figure 3-4 (above) also shows how the growing reliance on software across the DoD (and hence USAF) enterprise was recognized a decade ago by then Under Secretary of Defense Pete Aldridge as a significant contributor to the growth in program cost, schedule, and performance shortfalls, including (but not limited to) the software sustainment phase.[76] The Panel notes that ALC-provided data shows USAF weapons system software sustainment costs have nearly doubled over the past decade (an increase from $483M in 2002 to $841M in 2011).

This growth stems, in part, from the increasing reliance on software in USAF weapons systems, as shown in Figures 3-3 and 3-4. This increasing reliance is also reflected in following figure that shows approximately a 30% increase in software sustainment hours at the three ALCs over the past eight years.[77,78,79]

---

[76] Aldridge, P. "Testimony to House Armed Services Committee."

[77] 76th Software Maintenance Group. "76 SMXG Manpower Hours."

[78] Rogers, K. "Identify Software Maintenance Trends for AF Scientific Advisory Board."

[79] 402nd Software Maintenance Group. "Summary of Major Software Trends."

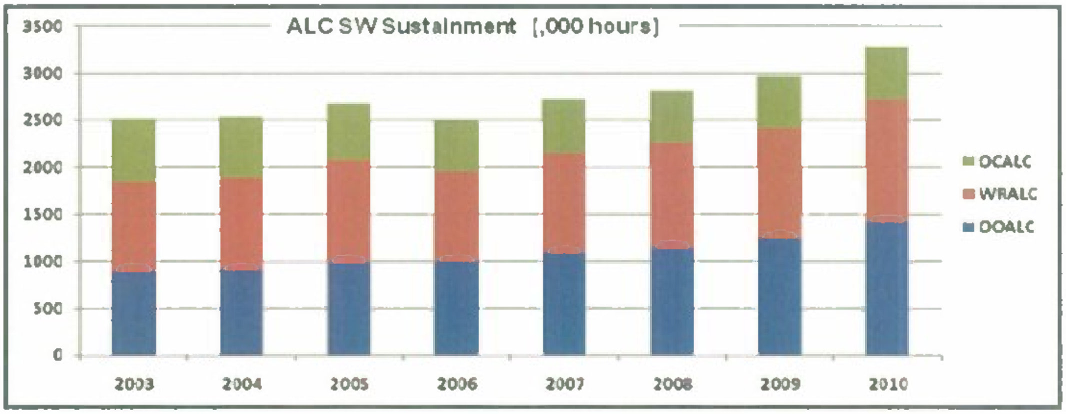


Figure 3-5. Increase of 30% in Software Sustainment Manhours at USAF Air Logistics Centers for the Years 2003-2010.

The ALC software sustainment effort shown in the figure above only considers hours billed against the operations and maintenance program element (the 3400 AF DoD appropriation account code). In practice, the ALCs indicated they also spend considerable time/effort on upgrades of legacy software (the 3600 and 3010 AF DoD appropriation account codes), though the actual apportionment of O&M versus upgrade work does not appear to match the appropriation account codes in a consistent manner. Analysis has shown that the full range of software sustainment activities (i.e., O&M plus upgrades) can account for 60-90% of the total lifecycle software costs.[80] The high level of software sustainment costs occurs for a number of reasons, including:

- Software-enabled capabilities are replacing hardware in legacy systems,
- Software may be upgraded again and again over the lifecycle of an airplane, and
- The original design intent of developers is often hard to discern, thereby complicating modifications and verification/validation activities.

Since sustainment is a lagging indicator, organic software sustainment costs are expected to grow significantly over the next decade as the current generation of USAF aircraft, such as the F-22 and F-35, transition from production to sustainment. Since these newer aircraft are considerably more reliant on software than legacy aircraft, the software sustainment costs should thus increase accordingly as they age. Also, the Panel was informed[81] that as advanced systems are introduced to legacy aircraft (e.g., the AESA radar for the F-15) these software-driven systems are driving up the software sustainment requirements for these aircraft as well.

---

[80] United States Air Force Software Technology Support Center. "Guidelines for Successful Acquisition and Management of Software-Intensive Systems: Weapon Systems, Command and Control Systems, and Management Information Systems (Condensed Version)."

[81] SAA Study Panel visit to Warner-Robins Air Logistics Center, Robins AFB, GA, February 16, 2011.

Another factor affecting the economics of sustaining aging aircraft is the fact that software sustainment costs do not scale with the number of aircraft in the USAF inventory, but instead scale with the number of MDSs and variants. Unlike aircraft structures and hardware, where production costs represent a significant expense, there is essentially no production phase for software, other than installation (where deployment and configuration management may be an issue). Hardware sustainment costs will therefore decrease as the USAF reduces the number of aircraft, but software sustainment costs will not because a weapon system generally needs the same software sustainment, whether it is a fleet of 10 aircraft or 1,000 aircraft.

The mix of government and contractor work is defined by a DoD Instruction (DoDI)[82] that designates that statutory requirements must be met prior to Acquisition Milestone B. The Core Logistics Analysis/Source of Repair Analysis further states that Title 10 United States Code (USC) 2464 (Core) and Title 10 USC 2466 (50/50) requirements must be addressed. Compliance with these requirements increases the complexity of the overall environment and challenges planners. Consequently, the transition from OEMs to ALCs is often not seamless, predictable, or cost effective, due in part to the lack of an enterprise-level USAF strategy for software.

For example, software sustainability considerations are often not included in program acquisition strategy and cost estimations for new digital capability. In particular, contracts many times fail to procure source code, necessary licenses and data rights, and technical data on V&V facilities and procedures during the acquisition process. The absence of this material may significantly complicate software sustainment and increase total ownership costs over program lifecycles. Moreover, a large investment is needed to reproduce OEM facilities (e.g., Software Integration Labs).

Another problem stemming from the lack of an enterprise-level USAF strategy for software is changing initial program premises, from CLS to organic support, which results in a worse case situation that drives duplication of contractor developed capability, increased government training requirements, and loss of domain expertise (contractor). Initial software logistics approaches need careful consideration and execution to avoid these pitfalls. If this transition is not adequately planned, the sustainment of the front-end contractor architecture, hardware, firmware and software design and development capability and the largely later government-phase software maintenance and modernization will be jeopardized. Without the ability to effectively incentivize contractors in the early program phases and to maintain some support throughout the lifecycle of the MDS, there is a potential to evolve to a situation where the capability is either permanently lost or too expensive to reconstitute. Maintaining the right mix of contractor and government participation in the software development and sustainment environment is essential to individual program success and long-term domain effectiveness.

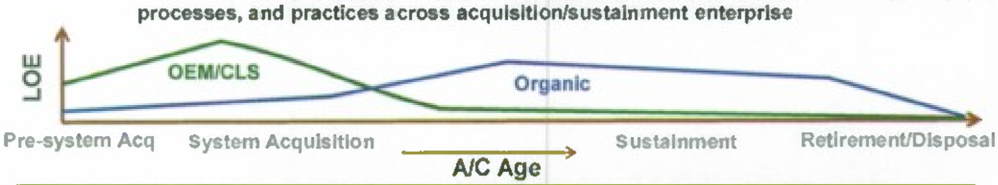
Yet another problem stemming from the lack of an enterprise-level USAF strategy for software is the current vacancy and, thus, absence of a long-term technical senior leader for the Computer Systems and Software Integrity Program that should provide software technologies

[82] United States Department of Defense. "Department of Defense Instruction 5000.02: Operation of the Defense Acquisition System."

and verification/validation methodologies. Most technical disciplines (propulsion, structures, and avionics) are represented by senior leaders at ASC and other locations. What is needed in CSSIP is a senior leader who is a recognized expert in software development, who can integrate and coordinate software sustainment efforts across AFMC/A4, the Electronic Systems Center, the Aeronautical Systems Center, and the Software Maintenance Groups at the ALCs, AFRL, etc. Likewise, the amount of research at AFRL devoted to sustaining legacy software appears quite small, relative to the amount of resources expended on sustaining legacy aircraft in the USAF.

Recommendation 3
Manage Software Over A/C Lifecycle

- USAF should adopt an enterprise approach to software sustainment throughout the lifecycle of an MDS [OPR: AFMC]
  - Form enduring, time-phased collaborations with A/C and A/C system OEMs for predictable and cost effective software sustainment as illustrated below
    - Collaborate with OEMs to leverage latest technical advancements and lessons learned
    - Ensure well-trained organic support available to perform capability upgrades for legacy platforms/components no longer supported by industry
  - Mature CSSIP rapidly to establish disciplined processes and technologies to meet software qualification standards and V&V over MDS lifecycle
    - Sponsor targeted software R&D with AFRL, research community, end ALCs, e.g., Software V&V techniques and refactoring/refresh methods/tools for legacy systems
    - CSSIP leadership requires in-depth software expertise to coordinate software principles, processes, and practices across acquisition/sustainment enterprise



Contractors and ALCs play distinct roles over the aircraft lifecycle

26

Given the strategic importance of software to sustaining aging aircraft, the Panel recommends that the USAF adopt an enterprise approach to software sustainment throughout the lifecycle of each MDS. The goals of such an enterprise approach are to ensure program acquisition and sustainment strategies reflect and protect the USAF investment in software by enacting robust software engineering processes/practices throughout the USAF and enabling the continued success of organic software activities at ALCs. At the heart of this recommendation is the recognition that effective software sustainment requires USAF investments and commitments throughout the lifecycle of each MDS, as shown in the above chart.

To address the development of an enterprise-level USAF strategy for software that facilitates sustainment over the MDS lifecycle, the Study Panel recommends the USAF facilitate and incentivize collaboration activities between OEMs and ALCs to ensure seamless transition of responsibilities and workload, as shown schematically in the Recommendation chart above.

Figure 3-6 below shows a recommendation for ALC involvement early in the program lifecycle to ensure well-trained organic support is available to perform capability upgrades when legacy platforms and components are no longer supported by industry. Likewise, the CLSs should be involved throughout the sustainment phase to ensure the ALCs can take advantage of latest technical advancements and lessons learned. Whenever feasible, the Panel recommends the USAF procure source code, negotiate necessary licenses and data rights, tech data on V&V facilities and procedures to simplify software sustainment and decrease total ownership costs over program lifecycles.

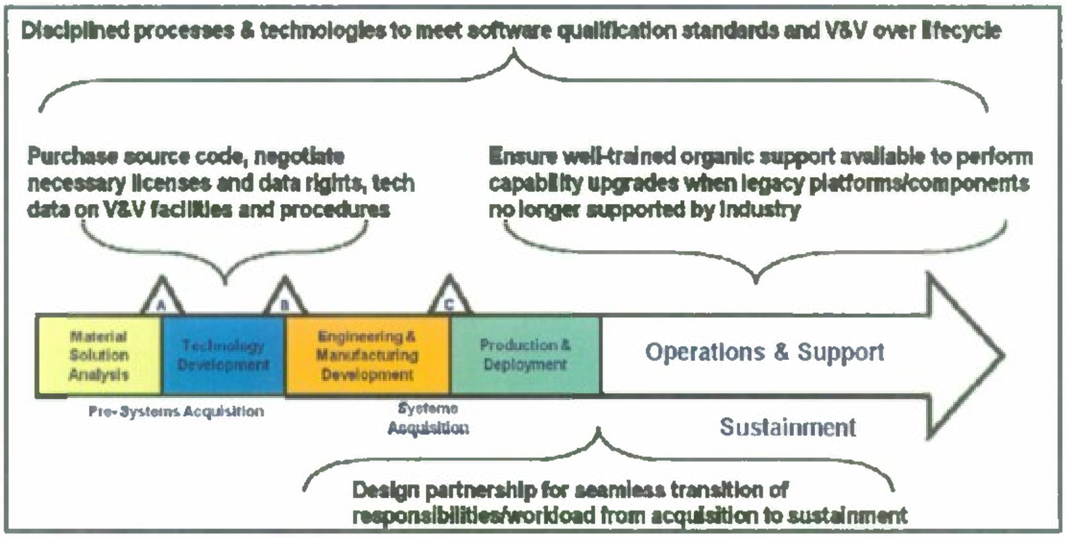


Figure 3-6. Weapons System Lifecycle versus Software Activities.

To address the finding that software use/complexity and rapid technology refresh have grown faster than the USAF's ability to address it across the lifecycle, the Panel recommends that the USAF fill the CSSIP manager position in ASC/EN with a senior leader with significant technical software expertise who is responsible for instituting and enforcing disciplined software principles, processes, and practices across the USAF enterprise, including (but not limited to) the following activities:

- Work with other senior leaders, researchers, and software engineers to help refine the USAF technical software strategy.
- Define the strategic direction and growth of the USAF technology in the areas of software-reliant weapons systems.
- Provide visible leadership for the USAF within the software research and development (R&D) and technology communities.
- Anticipate and react to major technology changes to ensure USAF software success and growth in a globally and nationally competitive landscape.
- Help to establish technical standards for software and ensure adherence to them for USAF R&D and O&M.
- Help to formulate and execute the technology strategy for USAF technology platforms, partnerships, and external relationships.
- Coordinate targeted software R&D with AFRL, the research community, and ALCs, such as software V&V techniques (e.g., via the CSSIP) and refactoring/refresh methods/tools for legacy software-reliant weapon systems.

Finding 4
Maintenance S&T Has Low Priority

- **AFRL devotes ~3.5% of its budget to sustainment S&T**
  - **Considerable fraction of sustainment S&T portfolio is for capability upgrades rather than maintenance technology development**
- **Maintenance S&T is technically rich but not considered leading edge science by many in R&D community**
  - **Corrosion understanding/prevention, crack initiation/growth prediction, robotic NDI approaches, legacy software V&V, etc.**
  - **Advanced AF maintenance technology efforts focused on future materials at expense of current fleet materials**
- **Maintenance S&T seldom bridges the "Valley of Death" transition**
  - **MAJCOM "pull" for maintenance S&T tends to be weak; resources favor R&D for capability enhancements**
  - **Issue well recognized by AFMC and AFRL, e.g., Greybeard Study**

Sustaining legacy USAF aircraft hasn't received adequate S&T attention

27

The Air Force Research Laboratory is the primary entity to address maintenance science and technology for the USAF. In fact, approximately 3.5% of the AFRL budget is currently devoted to overall sustainment science and technology.[83] However, the distribution between maintenance technology development and capability upgrades is heavily weighted towards capability upgrades. Given the increasing demands of maintaining an aging fleet of aircraft combined with a reduced likelihood of introducing a significant number of new aircraft technologies, there is an ever expanding need for a better understanding of maintenance science and technology issues.

AFRL is doing a commendable job in maintenance science and technology given its limited resources. It is understood that the disciplines which impact maintenance science and technology are intellectually stimulating and technically rich, but they are not perceived to be at the cutting edge of science by the scientific community. In fact, AFRL supported research in many important aging aircraft topics, especially those focusing on corrosion, stress-corrosion cracking, and crack initiation, have been degraded or eliminated in the last few years. On the one hand, these topics represent areas of research that have been ongoing for decades. On the other hand, these topics are becoming more relevant as the age of Air Force aircraft are extended beyond the age associated with their original design lives. In other areas, including NDI and

---

[83] Stevens, K. "Air Force Research Laboratory Sustainment Investment."

legacy software verification and validation, significant research is required to meet the demands of the ALCs.

AFRL is active in sustainment science and technology, but most of this effort is based in the study of advanced technologies, for example, composite materials, and therefore, AFRL is well prepared to contribute to S&T sustainment needs for future aircraft and components. For current fleet materials (i.e., aluminum), the S&T efforts are not as advanced but are rather pursing only evolutionary work such as the development of improved eddy current heads and the replacement of film in NDI with digital imaging.

An on-going issue with the research and development in sustainment by AFRL is the lack of transition from AFRL to industrial products. This so-called "Valley of Death" is, in part, related to the fact that the MAJCOMs do not provide a strong pull for the technologies that are supported by AFRL. MAJCOM funds tend to support R&D for capability enhancements so resources for maintenance S&T are weak. This is not a new finding; the problem has been widely acknowledged by AFRL as well as AFMC; the recent Greybeard Study[84] provides a similar finding.

In summary, the S&T investment in maintenance technologies has waned and must be resurrected if the Air Force is going to have the technologies required to maintain their legacy aircraft more affordably for the decades currently reflected in their plans. Greater attention is required here as the USAF moves into an era where sustaining aircraft becomes an increasingly important topic.

[84] National Academies of Science. "Greybeard Assessment of the Sustainment Technology Transition Process."

Recommendation 4
Increase Legacy Aircraft MX S&T

- Increase AFRL research efforts oriented to legacy aircraft maintenance needs and plan with the MAJCOMs for transition
  [OPR: AFMC/A4, AFRL]
  - Establish or increase fundamental R&D efforts in the following areas:
    - Corrosion, SCC, accelerated aging testing
    - Leak detection/prevention
    - Wiring fault detection
    - Software research in V&V, self-describing code, readability, interoperability, etc.
  - Mature promising hardware maintenance technologies to TRL 6 for technologies identified on following charts
  - Create full-scale demonstrations for maturing TRL 6 and MRL 6 maintenance technologies to implementation (TRL 9 and MRL 9)
    - Use return on investment justification beyond the FYDP time scale
    - Design an incentive plan that channels more funding into maintenance S&T or transition based on estimated cost savings

S&T investments are critical to reducing maintenance costs

28

The key recommendations are associated with increasing AFRL science and technology focus on research efforts that impact maintenance.

The first recommendation is that AFRL should reallocate its portfolio of research activities to increase research and technology efforts toward maintenance technologies in order to better address the materials issues associated with aging aircraft. As the Air Force becomes increasingly reliant on maintaining the performance of aging aircraft, AFRL should reflect this evolution in its own portfolio of activities.

Second, fundamental research in areas that are relevant to sustaining aging aircraft should be revitalized. Activities such as the establishment of Multidisciplinary University Research Initiatives are included in this recommendation. In particular, corrosion and stress corrosion cracking are becoming increasingly important for aging aircraft, especially with recent increases in demand and deployment in harsh environments. There are other areas that warrant attention including leak detection/prevention in tanker bladders that, for example, can draw on recent efforts in self-healing polymers. Wiring fault detection involves the daunting task of pinpointing a fault in long stretches of wire in complex wiring geometries; developments in a variety of electronics-based efforts are required to address this issue that spans the range of MDSs.

Given the dependence on software noted for both emerging and legacy aircraft for the Air Force, the following S&T topics are recommended for AFRL support for software sustainment

efforts at the ALCs (Note: Additional information on these R&D topics is available in "Software Maintenance and Evolution: A Roadmap[85]):

- Automated testing methods and tools to ensure that software changes work. Quality assurance for legacy software is often performed via manual testing, which is tedious, inefficient, and error-prone. A more effective approach is automated testing, which involves developing methods and tools to perform unit tests and integration tests efficiently and repeatedly. An example of a relevant R&D project on this topic would be distributed continuous quality assurance.[86]

- Legacy reverse engineering techniques and environments to recover/refresh software assets that are difficult and/or expensive to sustain. Examples of relevant R&D projects on this topic include program comprehension methods and tools[87] to enhance cognitive understanding of legacy software so it can be refactored, maintained, and updated without introducing new defects or degrading existing capabilities.

- Sustainment processes and methods to define, measure, and improve quality and reduce software risk.[88] Examples of relevant R&D projects on this topic include the Team Software Process, which provides a disciplined operational process framework designed to help teams of managers and engineers organize, produce, and sustain large-scale software projects of sizes beyond several thousand lines of code.[89]

- Traceability link recovery to identify/associate legacy software requirements, documentation, and code. Examples of relevant R&D projects on this topic include team-based software tools that enable each line of code in modern tool-enhanced code bases to have direct links to its complete history, including which developers have modified that line of code and for what purpose the modifications occurred.[90]

---

[85] Bennett, H., & Rajlich, V. "Software Maintenance and Evolution: a Roadmap."

[86] Note: More information on distributed continuous quality assurance research may be found on-line at: www.cs.umd.edu/projects/skoll.

[87] More information on theories, methods, and tools associated with program comprehension and reverse engineering may be found in: Storey, M. "Theories, Methods and Tools in Program Comprehension: Past, Present and Future."

[88] These and other processes and methods for software sustainment are discussed in: United States Air Force Software Technology Support Center. "Guidelines for Successful Acquisition and Management of Software-Intensive Systems: Weapon Systems, Command and Control Systems, and Management Information Systems (Condensed Version)." In particular, see Chapter 16.

[89] The Software Engineering Institute maintains a website resource with considerable information on the Team Software Process at http://www.sei.cmu.edu/tsp/ which can provide additional information on the Team Software Process.

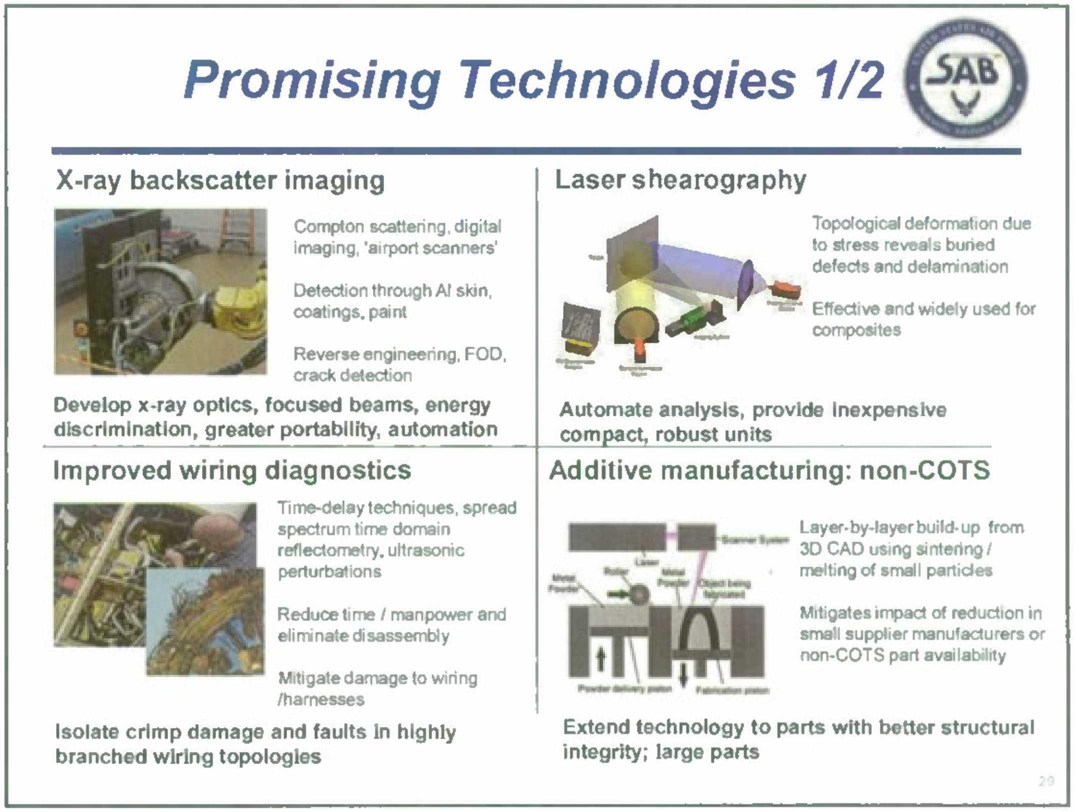
[90] These tools associated with traceability are discussed in Chapter 4 of the NRC Report Critical Code: Software Producibility for Defense. Note: This report is currently available on-line at: www.nap.edu/openbook.php?record_id=12979&page=R1.

In addition to the fundamental efforts at AFRL, there are several promising technologies whose further development could be very beneficial for depot and field-level maintainers. Given the clearly expressed needs emanating from the ALC (and related) briefings for technological assistance with many of their maintenance tasks, it is recommended that AFRL should advance many of these technologies through a combination of in-house and externally funded programs.

The development of these promising technologies will not be utilized to their fullest potential if they are not transitioned from the laboratory (TRL 6 or MRL 6) to production (TRL 9 or MRL 9). Therefore, it is very important for AFRL and AFMC to create a mechanism to drive the maturation of these technologies from TRL/MRL 6 to TRL/MRL 9. Towards that end, the Panel makes the following suggestions:

- Restructure the sustainment technology process to provide a single point of responsibility for technology transition at the ALCs.
- Establish formal guidance for sustainment technology development, transition, and implementation.
- Identify a portfolio of funding sources for transition and implementation.
- Establish quantitative measures for sustainment technology investments.
- Establish a Chief Technology Officer at each ALC.
- Increase senior logistics presence in AFRL.
- Create system support organizations in other AFRL technical directorates.
- Increase ManTech funding to focus additional resources on sustainment.
- Consider pilot programs to implement pervasive sustainment technologies.

While unlikely that all of these recommendations will be executed, implementing even a portion of them could bring significant results as the current level of maintenance technology development and implementation is relatively low.



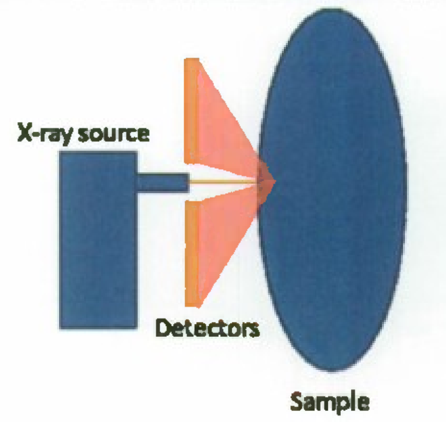
During the course of this Study, the SAA Panel received requests from the Air Logistics Centers, etc., for technologies to assist with several maintenance items. Several technologies, whether observed during one of the commercial visits or at an AFRL presentation, showed significant potential to assist with the sustainment effort. Some technologies may be mature for certain applications, but may require miniaturization, automation, or technological developments to be more effective for the sustainment effort. Eight topics are highlighted here for inclusion in future AFRL programs. Each topic summary includes a description of the technique, its current applications, and suggestions for how, with investment, the technique can be improved for sustainment applications.

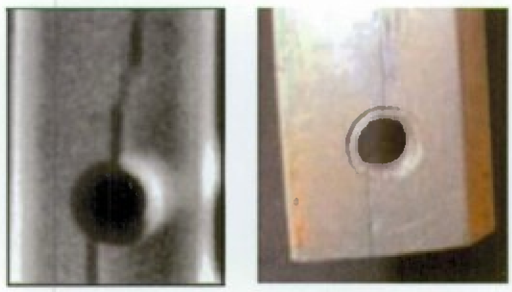
X-ray Backscatter

X-ray Backscatter Imaging provides a means to image structures under the aluminum skin. The technique utilizes Compton scattering, which is particularly strong in the back-scattered direction.[91] This feature differentiates it from the standard x-ray imaging technique, which relies on radiographic transmission (such as a dental or medical x-ray). The technique exploits the fact that Compton scattering is dependent upon the atomic density and the difference in absorption and scattering cross section of the target materials that create differences in

[91] Georgeson, G., Edwards, T., & Safai, M. "Boeing Scatter X-ray Imaging (BSXI) System."

baekseatter intensity, ereating eontrast within the reeonstrueted images.[92] White radiation, with a maximum in the 100-200 thousand eleetron-volts (keV) range, is eollimated into a beam of approximately 1 millimeter (mm) diameter and is scanned across a part; the backscattered radiation is imaged with a group of planar deteetors as shown sehematieally in Figure 3-7 below. This teehnology, based on researeh at the University of Florida,[93] was reeently adopted in industry[94] based on a eommereial produet by a eompany ealled NueSafe, Ine. The teehnology was initially employed for reverse engineering – finding modifications or non-standard ehanges to aircraft without extensive skin or support structure removal. Later, it was seen to help provide a means for foreign objeet deteetion in struetures, and more reeently, the teehnique has shown promise for observing stress-indueed cracking.





Schematic of backscatter imaging system	A sub-mm crack observed via backscatter (left) and optical image (right)

Figure 3-7. X-ray Backscatter Imaging System Schematic with Comparison of Backscatter and Optical Imaging Products.

In a typieal x-ray baekseatter measurement for a large area inspection, the following conditions are employed. The x-rays are generated from a tungsten-target x-ray tube operating at 160 keV and 10 milliamperes. The beam is eollimated to approximately a 1 mm diameter. The deteetor pixel dimension is approximately 1 mm. The beam is rastered vertieally over a distanee of several em and is seanned laterally with a veloeity on the order of 300 mm/min. The distanee

[92] Meng, C. "Computed Image Backscatter Radiography: Proof of Principle and Initial Development."

[93] Ibid.

[94] Georgeson, G., Edwards, T., & Safai, M. "Boeing Scatter X-ray Imaging (BSXI) System."

between the x-ray beam and the surface, or the so-called stand-off distance is approximately 75 centimeters (cm) to the surface.

In terms of personnel safety, the backscatter system is significantly less intrusive, and therefore safer, than x-ray radiography measurements based on transmission techniques. The latter employs higher power (somewhat higher energies but especially much higher currents) and requires that all personnel vacate the room in which the measurement is made; it is the remnant direct beam that is measured. Measuring backscatter eliminates that requirement and limits the standoff area to an arc whose radius is just a few times greater than the distance between the x-ray source and the sample to be imaged.

For crack detection, the ability to image a crack depends on the detector pixel size; therefore smaller pixel detectors are usually required. In addition, scanning speeds are slower and thus, the total range is reduced, so there is a trade-off between speed and sensitivity. It has been shown[95] that x-ray backscatter can detect cracks with a width of 0.02 mm and a length of approximately 2 mm in stainless steel under about 4 mm of steel. While a similar study of Al has not been published, NucSafe, Inc demonstrates that their system can readily detect cracks at 50 microns (μm) and can reduce this by an order of magnitude with minor modifications and some advances to the equipment (D. Shedlock, Director of Scatter X-Ray Imaging, NucSafe, Inc., Personal Communication, June 11, 2011). There are several approaches by which the system performance can be significantly improved. For example, implementation of microsource x-ray tubes can offer greater flux (not just flux density) over a smaller beam dimension (approximately 50-100 μm compared to 1 mm), often requiring only air cooling. Of course, there are significant technological challenges to producing an effective microsource system that operates at such high energies, and this represents an area for potential AFRL support. The incorporation of energy sensitive detectors, use of multiple beam energies, and custom detector apertures represent other advances that beneficially exploit the physics of Compton backscattering.

For NDI, the current x-ray backscatter systems are small enough to be mounted to a robotic mount or a gantry. Future systems can be made even smaller. This presents an evolution in addressing how large-scale NDI is performed. In the past, entire rooms or hangars were dedicated to inspection of an entire aircraft and the room would be evacuated when testing was being performed. Alternately, parts that were removed for maintenance were also inspected. With a robotic-based system combined with the small exclusion zone of the backscatter technique, it is conceivable that inspection can be carried out in a wide variety of locations (depots, bases, or airfields) under automated conditions in parallel with other maintenance procedures. Such an approach allows for optimized testing – the scanning rate and resolution can be tailored to the tolerance of the crack size at rivet holes at different locations, for example.

---

[95] Babot, D., Berodias, G., & Peix, G. "Detection and Sizing by X-ray Compton Scattering of Near-surface Cracks under Weld Deposited Cladding."

Smaller, self-directed versions would offer even more flexibility in the inspection process by allowing the units to 'crawl' over the aircraft, both on the surface and from the inside.

Laser Shearography

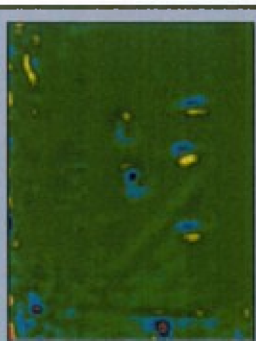
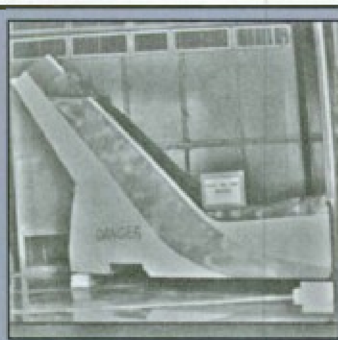
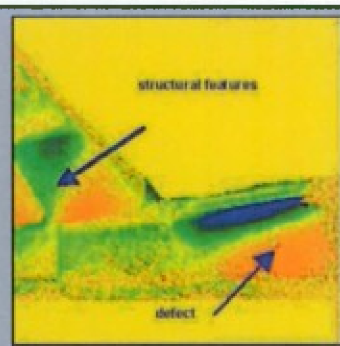
		
80 cm x 60 cm shearographic image of a rotor blade.	**Helicopter tail unit**	**Laser shearography image of tail unit after thermal loading**

Figure 3-8. Examples of Laser Shearography.

Laser Shearography utilizes a shearography camera, which includes a shearing lens and a detector. Laser light is reflected from a surface under inspection to the camera. A beam splitter and two mirrors produce two separate images of the illuminated area, and a speckle pattern is produced by the interference between the direct image and the sheared image, which are both sent to a charge coupled device detector.[96] This provides for something of an internal reference in that the speckle pattern remains the same even if there are vibrations or slight movements of the part. Next, a stress is applied to the part. The stress can be mechanical, thermal, acoustical, or pressure induced. Under stress, the sample deforms and a slightly different speckle pattern is produced. If the deformation is non-uniform, part of the surface (with a delaminated region underneath, for example) will deform differently than other parts. The difference between the unstressed and stressed speckle produces a fringe pattern, which depicts the relative displacement of the surface. Therefore, the fringe pattern corresponds to the derivative of displacement (strain) with respect to the shearing direction. (Holography, on the other hand, directly shows displacement rather than the derivative). The image is processed and, with information about the mechanical properties of the structure, one can determine the stress that is introduced. More importantly, the size of the non-uniform deformation is the size of the fringe pattern feature. The scale of the part that can be imaged is not limited. The system can be rastered across large areas (on the order of up to approximately 1,000 square feet per hour), covering entire sections of an aircraft.[97] On the other hand, with careful measurements and

---

[96] Pezzoni, R. "Laser-Shearography for Nondestructive Testing of Large Area Composite Helicopter Structures."

[97] Newman, J. "Aerospace NDT with Advanced Laser Shearography."

slower scanning, sub-micron defects can be imaged. Some examples of the output of shearographic scans are shown in Figure 3-8 above.

Improved Wiring Diagnostics

There is a need for techniques to diagnose a variety of wiring faults such as damaged/deteriorated insulation and faulty crimps. Electrical and ultrasonic techniques are among the possible approaches for nonintrusively identifying damaged/faulty wiring and for pinpointing the locations of faults. Pinpointing such faults poses a substantial technical problem since the speed of an interrogating signal may be a substantial fraction of the speed of light, 3×10^{10} cm per second, or equivalently 30 cm per nanosecond. Accordingly, straightforward time-delay techniques will benefit from the availability of ultrafast electronic components capable of detecting signals reflected from fault locations. Advances in such techniques portend:

- Effective wiring inspections without disassembly,
- Reduction of the time and manpower required to diagnose wiring, and
- Mitigation of damage to wiring and wiring assemblies including harnesses.

Among the physical phenomena and technical approaches underlying such wiring diagnostics[98] are:

- Ultrasonic detection techniques,
- Time-delay electrical techniques,
- Ultrafast diodes such as double-barrier quantum-well structures for resonant tunneling diodes that have frequency cut-offs of 100s of gigahertz, and
- Spread spectrum reflectometry techniques that facilitate the diagnosis of common but difficult-to-handle intermittent faults using
  - Application specific integrated circuits and
  - Correlation techniques that borrow from spread spectrum communications techniques.

These spread spectrum techniques rely on the injection of a pseudo noise code that is self-correlated to capture the characteristics of the wiring system including its branches, sources, loads, etc. Laboratory measurements indicate that these spread spectrum reflectometry techniques are capable of pinpointing the locations of faults to within a few centimeters in wiring networks containing over 50 meters of wire.[99] Given the limited fault location accuracies obtainable using both time-delay and spread spectrum techniques, it may be desirable to develop

---

[98] Griffiths, L., Parakh, R., Furse, C., & Baker, B. "The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location."

[99] Schneider, L., et. al. "A New Method for Detecting and Locating Insulation Defects in Complex Wiring Systems."

wiring diagnostic systems for localized bundles of wiring. These wiring diagnostic activities span the R&D budget categories and portend enhanced ability to diagnose faulty wiring with reduced damage during wiring inspections.

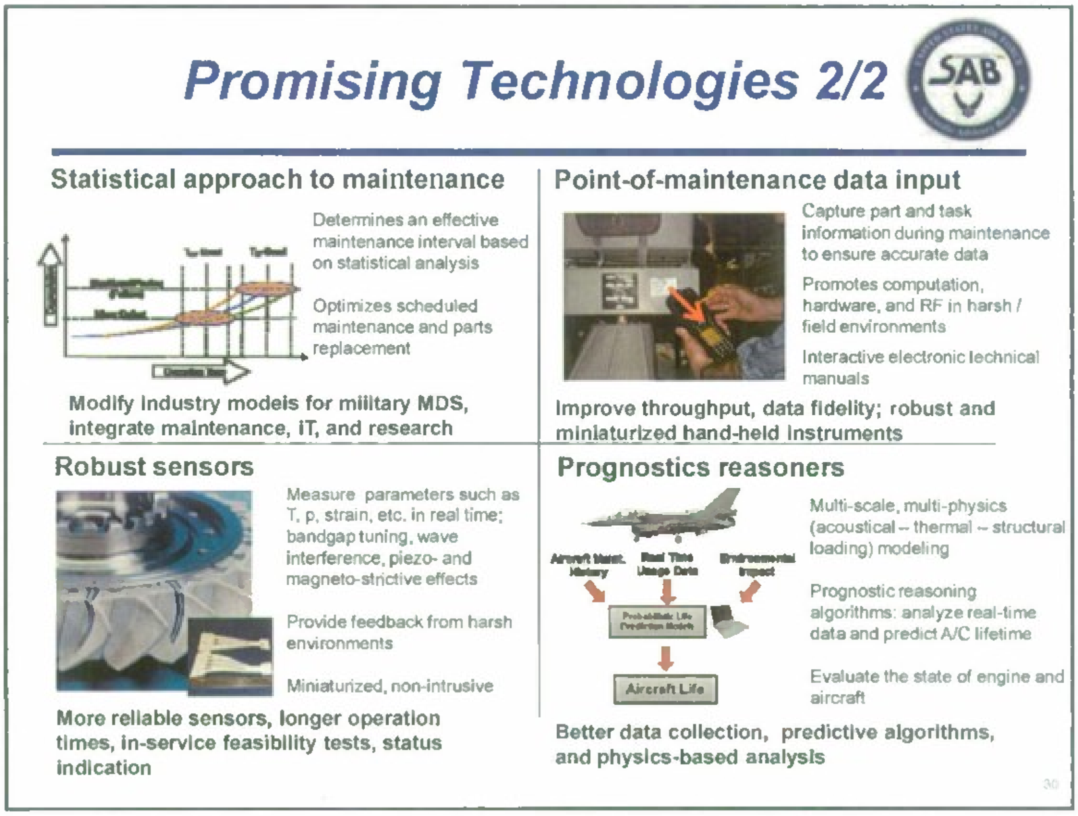
Additive Manufacturing

Additive Manufacturing is the process of producing parts from three-dimensional (3D) modeling data by adding successive layers of material rather than conventional or subtractive manufacturing processes. In this process, polymeric or metal materials are built-up to the geometry defined by a 3D digital model. The primary processes for building these materials involve sintering (metals) or melting (polymers) in a layer by layer fashion.[100] Additive Manufacturing allows for building parts with very complex geometries with limited or no use of tools and fixtures, and with the production of relatively small amounts of waste. There are a host of proven technologies utilized in advanced manufacturing. These include selective laser sintering, electron beam melting, aerosol jetting, and fused deposition modeling. Next generation enhancements involve Ultrasonic Additive Manufacturing, which uses sound to merge layers of metal drawn from featureless foil stock. The process produces nanoscale metallurgical bonds with full density and works with a variety of metals.[101] Additive Manufacturing makes sense for non-commercial off the shelf (non-COTS) parts as the lot sizes are generally too small for commercial manufacturers to find their manufacture profitable.

---

[100] Kalpakjian, S., & Schmid, S. "Rapid Prototyping Operations."

[101] Schick, D., et. al. "Microstructural Characterization of Bonding Interfaces in Aluminum 3003 Blocks Fabricated by Ultrasonic Additive Manufacturing."



Statistical Approach to Maintenance

Given the wealth of data that exists in the maintenance and logistics databases, and assuming that methods are developed that allow that data to be searched and sorted, statistical methods can be applied to improve sustainment efficiency. Examples where statistical approaches may benefit sustainment include: access-enabled maintenance, identification of correlated maintenance needs, refinement of mean time between failure (MTBF) statistics, and correlation between recurring maintenance needs and environment. Such statistical approaches could help maintainers to better understand the maintenance needs of an incoming aircraft.

Access-enabled maintenance refers to the opportunity to perform additional maintenance and inspection functions when access has been made to a particular aircraft component that needs maintenance. Establishing access to a component often incurs a substantial portion of the cost of a maintenance action. The act of obtaining access can, in itself, generate maintenance actions to components damaged in the process. A statistical database of component failure rates, combined with information about components requiring similar access and a tail-specific component configuration with installation dates, can identify additional maintenance work packages to be performed while common access is established. The cost of these additional maintenance actions will likely be less than the cost of subsequently grounding the plane and gaining access to the failed component.

Identification of correlated maintenance needs involves mining the maintenance and logistics databases to identify seemingly unrelated components that seem to frequently require maintenance/replacement during the same maintenance event. Such correlated maintenance

actions may identify previously unknown correlations between seemingly different sub-systems and components. There could also be correlations between component failures and operational environment (e.g., sand, humidity, salt air, low temperatures).

Maintenance and logistics databases can be used to refine estimates of component MTBFs and relate them to maintenance cost. Such statistics could reveal the emergence of counterfeit parts, degraded supplier performance, and appropriate inventory levels as well as the cost-benefit of component redesign/upgrade or supplier recompetition.

While there is a clear benefit to using the extensive databases to identify these statistics, there is an added benefit to seeing how these statistics change with time. The latter provides trends that can help identify emerging maintenance needs and solutions before they become an emergency.

Wireless Interrogation Technologies

New technologies show promise for remote or noninvasive inspection, reducing costs, compiling data, and reducing cataloguing error as well as missed defects. While these technologies are still in early stages, a sustained research effort is likely to produce workable technologies in the near future.

At the current stage, the proposed technology would employ robust sensor technologies to detect mechanical defects in engine or structural components. Because maintenance data collection is central to aircraft maintenance, a key requirement for future technologies to be effective is to improve data input into databases. Traditionally, data have been input into terminals located at an aircraft maintenance unit facility, away from the site of the maintenance itself. This can lead to incomplete and/or inaccurate data. Discussed below is a newer approach, the Point-of-Maintenance system (POMX), which has been partially but not yet universally utilized. The idea is to reduce the data entry burden while increasing data accuracy through the use of laptop computers and handheld portable maintenance aids. By enabling data entry at the maintenance location via wireless local area network or batch storage, accurate data can be captured as the maintenance is performed.

Point-of-Maintenance Data Input

POMX is part of the eLog21 initiative sponsored by Headquarters Air Force/Logistics, Installations & Mission Support/Maintenance Management Branch (AF/A4MM) and managed by the Automatic Identification Technology Program Management Office at Wright-Patterson AFB. The system backbone comprises a wireless local area network, ruggedized handheld terminals for use by maintenance technicians, a dedicated server for receiving and synchronizing data, and laptop and desktop computers for interfacing and analysis.[102] Besides ensuring greater accuracy and completeness at the outset, POMX also provides an error-checking function through an intelligent interface.

---

[102] Cone, W. "Improving Maintenance Data Collection via Point-of-Maintenance (POMX) Implementation."

A statistical analysis performed in 2006 based on data from Randolph AFB concluded that in its current configuration, POMX provided no discernable improvement in reducing the number of data entry errors.[103] The same study suggested that this was partly because the system remains underutilized. In particular, network connectivity and user training emerged as the main barriers to past efforts and keys to successful implementation for future POMX endeavors. Recommendations for improvement included improvements in software error-checking capability and development of a regression model to assist in predicting when errors are more likely to occur. Further investments in improving the robustness of the components as well as wireless networks would be expected to expand the ability to perform such tasks remotely.

The presence of technical manuals at the point of maintenance is a related technology that can aid the maintainer. Interactive Electronic Technical Manuals are technical manuals in electronic format, allowing users to locate information more rapidly than in paper manuals. Switching to the electronic format results in cost savings, allows for better integration with other logistics systems, and leads to greater success rates in fault isolation.

These systems while automating the input task still rely on the diligence of the maintainer to input the data properly and at a low level of detail that takes time and effort. Linking these systems to the replacement part call out or ordering system has been shown to help identify more precisely what was done during the maintenance activity. The Boeing C-17 support team described to the SAA Panel[104] a system in which they automatically "clean" their data by using the part ordering system to link the parts to the maintenance record to better define the activity performed.

Wireless Information Transmission

The basic idea behind wireless transmission is to process information at the sensor and then transmit it wirelessly to a remote location. Initial information might be simple "yes" or "no" as to whether structural, subsystem, or wiring damage exists. The more computationally intensive portion is to locate the damage and determine its type and extent. This requires specialized algorithms using information about the properties of the structure along with its history.

The next step is to incorporate computation and wireless transmission into the damage detection and evaluation process. This is a promising technology that can potentially come online in the near to mid-term. Several possible realizations have been proposed. One operates by collecting data from sensors and processing it at the sensor location.[105] After processing, a wireless signal is transmitted, indicating the health of the structure. In this application, microcontrollers are employed for the computational phase, and transmission uses a wireless modem.

---

[103] Ibid.

[104] SAA Panel visit to The Boeing Company, Saint Louis, MO, March 11, 2011.

[105] Lynch, J., et al. "Power-Efficient Data Management for a Wireless Structural Monitoring System."

A different proposal uses lead-zirconate-titanate patches as sensors and actuators, using a wireless telemetry system and performing computations at the sensor location.[106] The telemetry system chosen was the Radiometrix ultra high frequency / frequency modulated data transmitter and receiver modules. These were chosen for their small size and low power requirements.

As of now, these remain proposals. However, technology is at the stage where prototypes can be built in the near term, and implementation could be effected in the mid-term. Aside from various materials improvement issues, and looking for new means of computation and wireless transmission, one problem that needs addressing is securing transmitted information, which remains susceptible to interception by unauthorized parties.

Robust Sensors

There is a need for more robust and more reliable sensors with longer operation times. These sensors are needed for tasks such as in-service feasibility tests and status indication. Research and development on microelectromechanical devices and other miniaturized, non-intrusive sensors portends real-time detection capabilities of physical parameters of temperature, pressure, strain, etc., in standard operating conditions as well as in harsh environments. AFRL and its extramural research arm, the AF Office of Scientific Research, are currently exploring some approaches to realizing robust sensors.

Among the physical phenomena underlying such sensors are:

- Piezoelectric interactions
- Wave interference in fiber optics structures, magneto-striction
- Surface acoustic waves that are modified by changes in temperature and pressure
- The temperature- and pressure-induced changes in the bandgaps of semiconducting structures, and
- Bandgap changes due to dimensional-confinement effects illustrated by the dependence of the bandgap of semiconducting carbon nanotubes (CNTs) with the diameter of the CNTs as well as with deformations of the CNTs. This wide variety of physical phenomena portends enhanced opportunities for research supporting sustainment of aging aircraft.
- Systems that monitor engine performance and vibration are already in use and need to be accessed remotely for rapid maintenance.
- Systems that monitor wiring integrity would be valuable for both manufacturing check-out and maintenance.

[106] Martin, L. "Developing a Self-Powered, Wireless Damage Detection System for Structural Health Monitoring Applications."

- Similarly, system monitoring capabilities would enhance detection of faults and replacement requirements long before depot servicing and relieve the long inspection times now required.

Prognostic Reasoners

Prognostic reasoning involves the continuous assessment and prediction of the current and future health of aircraft structures and systems. Life prediction involves knowing the state of health of a structure and predicting future degradations in strength as the aircraft is used. Sensors will evaluate the state of the engine and aircraft structures and systems. Prognostic reasoning algorithms will analyze real-time data coupled to current environmental effects and then learn, and calculate remaining aircraft life. Finally, future-mission needs and remaining life will dictate future asset allocation. The key S&T disciplines needed include:

Coupled Physics-based Models of Damage and Behavior

- Interaction of multiple damage/failure mechanisms
- Multi-scale, multi-physics analysis
- Microstructurally-based stochastic behavior
- Integrated information from state-awareness tools

Interrogation of Damage State

- Intelligently exploit existing sensors
- Feature extraction from global sensors
- Damage-state interrogation techniques and recorders

Data Management and Fusion

- Component history and pedigree
- Component usage data
- Capability matched to mission

Finding 5
Commercial Keys to MX Cost Control

- Airlines and OEMs emphasize reliability data collection and analysis
  - Emphasis on accurate MX data entry and information extraction to continuously improve processes
  - USAF operational units face data entry and extraction inefficiencies
- Airlines and OEMs utilize sophisticated maintenance practices
  - Advanced tools and techniques used to understand and resolve in-service issues
  - Focus on MSG-3 to optimize maintenance processes throughout life cycle
  - Perform maintenance where most economical, as much in field as possible
  - Rapid completion of major overhauls – depot stays of 30 to 45 days
- Airlines optimize contracting practices
  - Employ incentive-based contracts to stabilize operating costs
  - Use ROI calculations based on aircraft life
- FAA provides independent airworthiness oversight
  - Approves design modifications, repairs, and parts installation approvals
  - Has authority to mandate design and maintenance changes

Low O&M expenditures are vital to commercial profitability

31

Commercial airlines and maintenance providers have several practices that may be applicable to the Air Force. Airlines typically perform maintenance per MSG-3 practices (Valieka & Kizer, Personal Communication, 2011). One of the key elements of MSG-3 is the continual effort to refine and improve the maintenance process throughout the aircraft lifecycle. Data are required to make these refinements, so airlines place significant emphasis on accurate collection and analysis of the data.

Commercial airline OEMs utilize sophisticated tools to track the maintenance status of aircraft under their management. For example, Boeing Company has a 24/7/365 operations center that tracks the status of every aircraft. This facility consists of a highly automated aircraft tracking system with a large staff to monitor status and resolve issues. Analysts can easily access maintenance information for any aircraft tail number. Service requests are recorded, promise dates committed, and metrics tracked to ensure on-time closure of issues (R. Rakestraw & L. Berry, The Boeing Company, Personal Communication, May 24, 2011). Boeing also provides their customers a "toolbox" which provides extensive on-line information to maintainers including schematics, maintenance manuals, troubleshooting manuals, and pictures

of the component installation. This tool facilitates rapid troubleshooting and supply chain efforts to ensure the aircraft is returned to service as quickly as possible.[107]

The commercial airlines also make significant efforts to perform maintenance at the most economically advantageous location. For example, significant commercial aircraft maintenance is performed during overnight layovers using surge maintenance crews that perform the work within eight hours or less (K. Davis, Delta TechOps, Personal Communication, March 24, 2011). This practice allows the airlines to complete required maintenance while maximizing aircraft availability.

Commercial Airlines and MRO centers place a high emphasis on rapid completion of major overhauls. For example, a wide body aircraft major overhaul will be completed in 45 days or less. Narrow body overhauls are typically completed in 14 days or less (Valicka and Kizer, Personal Communication, 2011). As previously mentioned, this rapid turnaround is required to ensure the aircraft are rapidly returned to revenue service.

Commercial Airlines desire a stable and minimal risk operating cost environment. They partially achieve this goal through the use of incentive-based maintenance contracts from suppliers (K. Davis, Personal Communication, 2011). One example of this is "Power by the Hour" engine maintenance. In this program, the airline pays the engine OEM a fixed fee for each hour the engine is operated. The OEM then performs all maintenance on the engine and provides replacement parts as needed. This practice minimizes risk for the airline, and provides incentive for the OEM to fix engine reliability issues.

Another contracting practice used by commercial airlines is the application of return on investment (ROI) calculations more in line with the expected life cycle of the aircraft (Valicka and Kizer, Personal Communication, 2011).

A final notable commercial practice highlights the role of the FAA which provides continued airworthiness oversight over the complete lifecycle of a commercial aircraft. The FAA approves the initial design, all design changes, maintenance manuals, and any part installed on the aircraft. Further, the FAA has the legal authority to mandate design or maintenance changes through the Airworthiness Directive process.[108,109]

---

[107] Boeing Company. "Use of Technology to Speed and Simplify Maintenance of Commercial Aircraft."

[108] Federal Aviation Administration. "FAA – USAF SAB Discussion."

[109] Federal Aviation Administration. "SAB Sustaining Aging Aircraft Study: Discussion Topics for the FAA."

Recommendation 5
Emulate Commercial Best Practices

- **Institutionalize applicable commercial best practices [OPR: AF/A4, AFMC/A4/PK]**
  - **Improve quality and accuracy of MX data entry, searchability, and integration of databases to inform reliability analyses**
    - **Adopt advanced technologies to expedite MX data entry accuracy**
  - **Expand Reliability Centered Maintenance (RCM) practices**
    - **Incorporate MSG-3 approaches, e.g., preventive maintenance throughout field-level and depot-level sustainment enterprise**
  - **Improve contracting practices**
    - **Explore use of incentive-based contracting mechanisms**
    - **Utilize contract ROI calculations longer than 5 years commensurate with expected platform life**

Strengthened RCM and MSG-3 practices can enhance AA

32

The USAF Sustainment Enterprise could benefit from the adoption of selected practices used in the commercial airline industry. The selected best practices and rationale are the following:

Quality, Searchability, and Integration of Maintenance Databases

Under aircraft sustainment, this is currently being implemented by various methods and to varying levels by the Weapons System Integrity Programs. For example, the ASIP implements Individual Aircraft Tracking (IAT) based on usage, however for some MDSs acquiring valid usage data is very challenging.[110] The PSIP tracks usage in a similar manner for engines.[111] The MECSIP Program is creating a Functional Systems Integrated Database for all MDSs.[112] These databases are being created organically and by a number of different contractors, which may result in a lack of standardization across MDSs.

---

110 Babish, C. "USAF ASIP: Protecting Safety for 52+ Years."

111 Fecke, T. "Propulsion Integrity Program."

112 Condron, T. "Mechanical Equipment and Subsystems Integrity Program (MECSIP)."

These activities should be strengthened to focus on standardized integrated practices and the resulting database process should also be incorporated by the remaining two Integrity Programs, AVIP and CSSIP.

Reinvigorate Reliability Centered Maintenance (RCM) Practices

MSG-3 guidelines have been developed to provide the aircraft industry with a framework for creating scheduled maintenance plans that are acceptable to regulatory authorities, operators, and manufacturers. Air Transport Association's (ATA) Operator/Manufacturer Scheduled Maintenance Development (MSG-3) Revision 2001.1 document is accepted by the FAA as a guideline for scheduled maintenance program development.[113]

MSG-3 guidelines take a "top down" approach that looks at the potential effects of a functional failure and on the ability to detect the failure, as well as the costs of failure and of maintenance actions. According to these guidelines, the objectives of an efficient scheduled maintenance program are to:

- Ensure realization of the inherent safety and reliability levels of the aircraft.
- Restore safety and reliability to their inherent levels when deterioration has occurred.
- Obtain the information necessary for design improvement of items whose inherent reliability proves inadequate.
- Accomplish these goals at a minimum total cost, including maintenance costs and cost of failures.

There is a US Navy Management Manual (NAVAIR 00-25-403, Guidelines for the Naval Aviation Reliability-Centered Maintenance Process) that incorporates selected features of the MSG-3 guidelines into an overall Reliability Centered Maintenance Process.[114] During multiple Integrity Program Reviews for specific MDSs, NAVAIR 00-25-403 was identified as the standard selected for particular sustainment programs because it is a complete process from design to retirement. The Panel recommends all MDS Sustainment Programs reinvigorate rigorous process adherence to this RCM Process through the Weapons System Integrity Programs.

Improve Contracting Practices

Use of performance-based contracts increasingly drives Original Equipment Manufacturers (OEMs) to accept a large share of the risk for flight of aging aircraft. DoD mandates the use of Performance Based Logistics (PBL) contracts for all major weapons systems *acquisitions*, however not for legacy aircraft sustainment programs. PBL has tremendous potential to align USAF and supplier incentives and performance across a complex value chain.

---

[113] Ibid.

[114] Creating Initial Scheduled Maintenance Plans: Using the MSG-3 Aircraft Systems and Powerplant Analysis Process to Develop an Initial Scheduled Maintenance Plan.

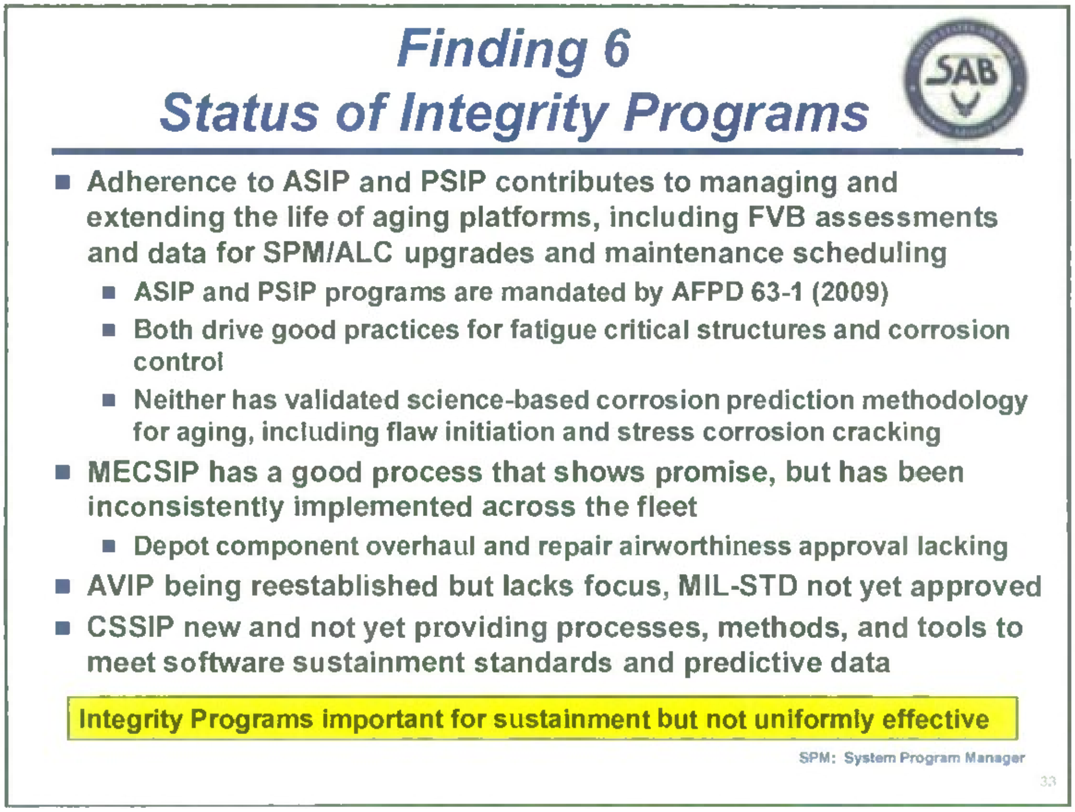
For both USAF and OEMs, developing the right contract terms to properly balance risk, expectations, and performance presents a real challenge. Tools, techniques, and experience with foreign military users are available to develop PBL contracts that are profitable, sustainable, and competitively priced.

Business assessments of sustainment contracts should consider contract ROI calculations longer than the required 5 year limit, potentially up to projected end of platform life.

Strengthen Airworthiness Oversight

Continued airworthiness for all MDSs is covered under an Air Force Policy Document (AFPD 62-6).[115] Generally this process provides centralized control with decentralized execution. Each MDS Program Manager and Chief Engineer has the responsibility to ensure airworthiness through ownership of Tech Orders and Maintenance Instructions throughout the lifecycle of the MDS. This is strongly coupled with the Integrity Programs (ASIP, MECSIP, PSIP, AVIP, and CSSIP). In order for a fully effective Continued Airworthiness program, all Integrity Programs must be matured to the level of ASIP and PSIP and brought to full functionality as soon as possible. The goal of these programs should be to provide the kind of independent oversight of aircraft integrity that can assure safe flight for all subcomponents in all mission types.

[115] Grimsley, F. "USAF Airworthiness Process Overview: Presentation To Scientific Advisory Board."



AFMC has recently turned over its role as airworthiness authority to ASC/EN in accordance with Air Force policy to tie airworthiness for both development and legacy programs into a common airworthiness process.[116] This process is to be supported and led by the integrity programs within ASC/EN. The flagship for these programs is the Aircraft Structures Integrity Program which was developed to counter significant structural fatigue (and eventually fracture) failures that occurred in the 1950s, when these behaviors were not well understood by the engineering community at large.[117] The ASIP program established fatigue and fracture mechanics as disciplines within the design community and within military specifications to ensure the durability and damage tolerance of future USAF aircraft. The fundamental science and engineering steps were followed by adoption into commercial aircraft and implemented by the FAA. Since that time, ASIP personnel have been instrumental in reviewing durability and damage tolerance issues and incidents within the Air Force, as well as commercial aviation, to ensure safety in these aircraft. They host an ASIP conference each year to review MDS

---

116 United States Air Force. "USAF Airworthiness (Air Force Policy Directive 62-6)."

117 Babish, C. "USAF ASIP: Protecting Safety for 52+ Years."

durability and damage tolerance experience and share best practices and technology advancements in these disciplines.

The status of the current Integrity Programs is shown in Tables 3-1 and 3-2 below:

	Attributes				
	Formed	Leader	Reports to AFMC	Tied to ALC	Tied to FVB
ASIP	1950s	SL (Babish)	Annually	Yes	Yes
PSIP	1970s	SL (Fecke)	Annually	Yes	Yes
MECSIP	1990s	GS-15 (Condron)	1 in 3 Years	Initiated	Initiated
AVIP	1990s	SL (Fraker)	N/A	N/A	N/A
CSSIP	2010s	SL (Vacant)	N/A	N/A	N/A

Table 3-2. Attributes of Current USAF Integrity Programs.

	Products			
	Requirements	MDS Plan	MDS Audits	Conference
ASIP	Mil-1563	Complete	All	Annual
PSIP	Mil-3024	Complete	In Work	Bi-Annual
MECSIP	Mil-1798	In Work	Initiated	First
AVIP	In Staffing	N/A	N/A	N/A
CSSIP	In Draft	N/A	N/A	N/A

Table 3-3. USAF Integrity Program Products and Processes.

The above tables show the attributes of each Integrity Program in terms of their duration, their leadership, and their ties to AFMC, ALCs, and the FVB. The second table shows the products of these Integrity Programs, whether or not they define airworthiness requirements for design and certification, whether they are involved in each MDS, whether they perform audits for integrity in their disciplines and whether they hold a conference to get concurrence on best practices and methods.

PSIP was initiated shortly after ASIP was found to provide substantial improvement in the structural integrity of USAF aircraft in order to provide the same level of disciplinary rigor and practice to engine design and sustainment that had been found to benefit structures.[118] Early in the establishment of PSIP, it was found that dynamic fatigue was a driver for wear out and failures in engines and could be monitored by sensing the components of the vibration harmonics of engines. Changes in amplitude of those harmonics could indicate that an engine was suffering wear in a component or part that would eventually cause a failure of that component. Engine

[118] Fecke, T. "Propulsion Integrity Program."

health monitoring became a standard practice for driving maintenance and engine replacement and repair. As these data were analyzed and studied, it became apparent that it would be possible to predict from the detection of these harmonics when failures of the components would occur and the severity of those failures on the health of the engine (whether they would be peripheral or catastrophic to the engine). This paved the way for prognostic health monitoring for engines that is coming into practice for new engines today.

MECSIP is a third step toward ensuring the integrity of aircraft systems. It was begun shortly after ASIP when those benefits were seen, but suffered a lack of strong technical leadership for a decade and failed to become as institutionalized as ASIP or PSIP.[119] Due to the unfortunate incident involving a T-38 actuator, MECSIP has been reinvigorated in recent months, has been brought under the ASC/EN auspices, has been asked to begin to hold an annual MECSIP Conference like that of ASIP to share best practices within the community, and is intended to review the state of the mechanical systems within aircraft in the USAF inventory. The MECSIP community is just starting to understand the kind of data and knowledge base that will be required to design, qualify, and maintain these systems in the future.

AVIP is the fourth component of the Integrity Programs and deals with avionics components since their lives and failure modes are somewhat different from those of mechanical and hydraulic systems.[120] This area is not following the path outlined by ASIP, PSIP, or MECSIP and thus appears to be less coordinated with the others and more independent. This seems to have occurred despite the successes of the other elements of the Integrity Programs and may be causing it to encounter resistance in accepting its processes as a Military Standard. AVIP has not yet developed the standards, data, and knowledge base required to identify failure modes, causes, and conditions that drive lifetimes for their components.

CSSIP (computer systems and software integrity program) is the fifth leg of the Integrity Programs and is the youngest and least formalized of the programs.[121] Yet, as more functionality is implemented through software than hardware in newer systems, it may be the most important of the integrity programs in the future. Thus, it is crucial to accelerate the establishment of CSSIP as a vital and functioning part of the Integrity Programs.

These programs are intended to be an integral part of the USAF process to ensure airworthiness for both aircraft in development and older aircraft. For aircraft in development, the integrity program teams review the design and certification test process. For older aircraft, they not only review the maintenance, status, and airworthiness of older aircraft, but determine the requirements to maintain airworthiness for these aircraft as they approach or exceed their design service lives. Finally, these teams review accidents and failure incidents to ensure that solid engineering and science are brought to bear on the solutions proposed for these incidents and that the processes used to return the aircraft to service will ensure safe flight for the remainder of the projected service life of the aircraft.

---

119 Condron, T. "MECSIP Presentation to Scientific Advisory Board."

120 Haley, A. "Avionics Integrity Program (AVIP)."

121 Springer, D. "Computer Systems and Software Integrity Program (CSSIP)."

There are some lessons learned from this Study that seem to be predictors of success for these programs:

- First, Integrity Programs must have technically strong leadership that is committed to ensuring the life and integrity of USAF aircraft. It is a benefit to have a leader that is a nationally recognized subject matter expert. These people draw the experts from industry, academia, and the laboratories to ensure the best technologies are brought to bear on problems or design reviews in order to ensure that these best practices are incorporated into USAF aircraft.

- Second, these leaders must have the backing of senior USAF leadership so that when problems are detected or incidents occur which affect the safety of USAF aircraft, these fleets can be shut down, inspected, analyzed, repaired (if necessary), and returned to safe flight service. They must be an integral part of the USAF Airworthiness assurance process.

- Third, these Integrity Programs must be tied into the work done at the ALCs and be able to get data on faults, repairs, and equivalent flight hours. They must likewise work closely with the Fleet Viability Board to have an impact on the force planning decisions made by USAF.

- Fourth, these integrity programs should have reviews of USAF aircraft and an annual conference at which to share best practices and solutions to problems among industry, academia, and government leaders. These help ensure that best practices are shared and used by industry in future designs.

Recommendation 6
Strengthen All Integrity Programs

- Make entire suite of AF Integrity Programs an integral part of SPM lifecycle management plans, FVB evaluations, and flight worthiness certification [OPR: ASC/EN]
  - Bring MECSIP, AVIP, and CSSIP Integrity Programs up to the high level of rigor resident in ASIP and PSIP
  - Incorporate S&T advances in aging mechanisms and instrumentation into ASIP, PSIP, AVIP, and MECSIP:
    - Corrosion prediction methodologies
    - Stress corrosion cracking
    - Composite failure modes and strength prediction over time
    - Nondestructive inspection (NDI) techniques
  - Focus the AVIP process to provide the same elements as ASIP/PSIP and implement into the associated MIL-STDs
  - Mature CSSIP rapidly to establish disciplined processes
    - Software qualification standards
    - Verification and Validation over the lifecycle of the platform

Strengthened Integrity Programs are vital to continued airworthiness

34

This Study recommends that the entire suite of Integrity Programs, especially AVIP, MECSIP, and CSSIP, be brought up to the rigor that exists today in ASIP and PSIP. This is felt to be important for sustaining the fleet for lives that extend beyond the original design service life of an MDS. These programs provide data on usage and remaining life that are keys to lifecycle management plans, fleet viability assessments from the FVB, and flight worthiness certification.

Even though ASIP and PSIP are mature programs, it is the recommendation of this Study that these programs begin to incorporate aging parameters in addition to the usage parameters that they have traditionally used to monitor and predict life. Usage parameters are defined earlier in the report, but they include those driven by fatigue loads, system usage, chaffing, and wear. Age includes those degradation processes driven by environment, corrosion, stress corrosion cracking, sealant degradation, and wiring protection systems degradation due to UV and chemistry. It may be necessary to develop NDI processes that can detect the types of degradation that occur under these types of aging conditions.

The maturation of CSSIP needs to be accelerated to provide solid data and processes to ensure the safety of flight related software maintenance and upgrades as well as to ensure that verification and validation processes used by contractors and the ALCs support the flight certification of the system. CSSIP needs a nationally recognized software expert to lead the program so that it carries the technical weight necessary to implement its recommendations. It needs support from the ASC Commander to stand behind grounding decisions based on software issues when they affect safety. It needs to produce the data and processes required to manage,

monitor, and oversee the verification, validation, and certification of flight system software for USAF aircraft. These program elements are not generated rapidly; they require the concurrence of the technical community and the strong participation of the ALCs.

The Panel believes AVIP processes should parallel those of ASIP and PSIP. When briefed on AVIP,[122] the Study found that AVIP seemed to be taking a significantly different approach than that developed by ASIP and PSIP. While the Study Panel realizes that avionics are measured by mean time between failures rather than fatigue life, it is also known that usage (on/off cycles) drives many of the failures encountered in those systems. The Panel believes that there must be a way to more closely parallel the ASIP and PSIP models with AVIP and still have a viable means of measuring life used and time to failure. The Study Panel also believes that incorporation of those measures might ease the adoption of the AVIP process and help enable its Military Standard to find better acceptance.

MECSIP seems to have defined good, solid processes and metrics, but needs to secure the solid backing of the ALCs and ASC to become a functioning member of the integrity teams. The initial MECSIP Conference in 2011 was a good starting point for obtaining the industry, ALC, DoD, and academic endorsements required to provide a solid foundation for that program.

Eventually, all of the Integrity Programs must be fully functioning and providing sound technical measures of life expended and life projections under both usage dominated failure modes and age driven failure modes in order to be effective in helping to keep USAF aircraft flying safely beyond their equivalent design service lives.

---

[122] Haley, A. "Avionics Integrity Program (AVIP)."

Bottom Line

- Aging legacy aircraft will drive sustainment costs ever higher in the coming years
- Capability upgrades and sustainment of advanced technologies, especially software and avionics, will further stress budgets
- Introducing AA/$ efficiency metrics will allow the AF to gauge depot performance and explore efficacy of improvement programs
- Commercial airline practices, enhanced supply chain forecasting, more accurate MX data bases, and S&T maintenance advances will contribute to increasing AA and restraining cost growth
- Strengthened Integrity Programs will ensure airworthiness of aging, legacy fleets
- Maintenance S&T requires increased emphasis to contribute to life extension, expedited inspections, and reduced touch labor
- Approaches to transition technologies with promising ROIs need to be adopted to realize the benefits of S&T advances

35

The bottom line from this Study is summarized in this chart and expanded below.

Aging legacy aircraft will likely drive sustainment costs ever higher in the coming years. Given that failure modes based on chemical degradation are found as aircraft age, it is expected that depot maintenance will increase with USAF aircraft age. These will often occur as over and above as long depot maintenance cycles are determined by fatigue life usage.

Capability upgrades and sustainment of advanced technologies, especially software and avionics, will further stress budgets. Furthermore, software is expected to increase its pervasive intrusion into even hardware-related upgrades and eventually to functionality that is based on software upgrades alone. These upgrades are often crucial to attain war fighter advantages or transport efficiencies, but they will further increase the costs to retain these aircraft in the USAF inventory. Furthermore, these costs are independent of fleet size.

Introducing rigorous efficiency metrics will allow the Air Force to gauge depot performance and explore efficacy of improvement programs. ALCs have sufficient data on their processes to allow them to quantify their efficiency, but they need to define the metrics that allow them to do so. The Panel has recommended the cost of aircraft availability as one important metric. Once those metrics have been developed and validated, the ALCs can use the efficiency metrics to evaluate new processes and new initiatives that might improve throughput and reduce depot time for possessed aircraft.

Emulating commercial airline practices, efficiency enhancements, and science and technology maintenance advances can aid in increasing aircraft availability and restraining cost

growth. Commercial airline practices such as reliability centered maintenance, increased awareness of maintenance status and configuration prior to depot entrance, and high velocity maintenance through the depot can help reduce time and cost in depot. The efficiency enhancements and metrics described previously can help determine which of these enhancements drive true cost savings.

Science and technology can help reduce the time to gather configuration and maintenance data from aircraft coming to depot, to rapidly determine the damage state of the aircraft in depot, and to produce replacements for obsolete parts. Approaches to transition technologies with promising ROIs need to be adopted to realize the benefits of S&T advances.

Integrity Programs must be brought up the rigor and stature of the Aircraft Structural Integrity and Propulsion Systems Integrity Programs. The Mechanical Equipment and Subsystems Integrity and Avionics System Integrity Programs have begun to see renewed focus and a start toward viability. The Computer Systems and Software Integrity Program must be matured rapidly to provide the data and processes that will drive flight safety software toward validation and verification to assure continued airworthiness.

This Study Panel applauds the efforts of the sustainment community and their efforts to maintain aging USAF fleets and provide mission capable aircraft to operational wings and, thus, enable the best possible warfighting capability. It is the goal of this Study to enhance and enable the sustainment and research communities to meet the needs of sustainment for these aging aircraft for it is certain that the USAF will have these aircraft in the inventory for a long time to come.

Appendix A:
The United States Air Force (USAF) Sustainment Enterprise

This Appendix summarizes the various elements of the USAF Sustainment Enterprise and provides background information regarding how this enterprise operates to sustain the USAF's aircraft, determine fleet viability, and ensure the integrity and airworthiness of the Air Force fleet. It also includes a summary of the various legal and budgetary constraints under which this enterprise operates.

A.1 AFMC Aircraft Sustainment Centers

The Air Force (AF) has four aircraft sustainment centers as identified in Figure A-1 below. Three of these are Air Logistics Centers (ALCs) and one, AF Global Logistics Support Center (AFGLSC), provides logistical support. ALCs perform heavy maintenance on aircraft and subsystems. AFGLSC provides supply chain management to the ALCs and the Air Force fleet.

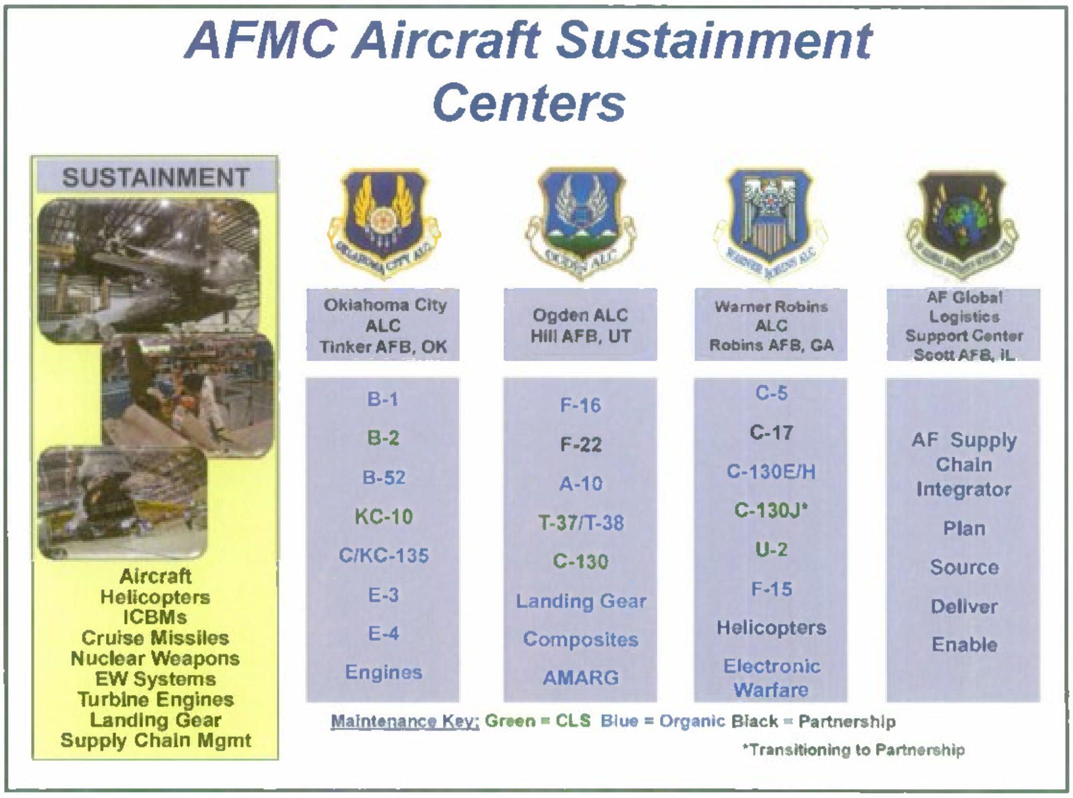


Figure A-1. The Four Current Air Force Materiel Command Aircraft Sustainment Centers.

A.1.1 Air Logistics Centers

The ALCs provide heavy maintenance for the types of aircraft (Mission Design Series, or MDSs) and other systems assigned to the facility. In addition, the ALCs provide maintenance for various components and subsystems. MDS responsibility is roughly divided amongst the ALCs in the following manner:

- Oklahoma City ALC: Bombers, Tankers, and Engines
- Ogden ALC: Fighters, Landing Gear, and Composites
- Warner Robins ALC: Mobility Aircraft, Helicopters, and Electronic Warfare

The Aerospace Maintenance and Regeneration Group (AMARG) is a one-of-a-kind specialized facility within the Air Force Materiel Command structure. AMARG provides critical aerospace maintenance and regeneration capabilities for Joint and Allied/Coalition warfighters in support of global operations and agile combat support for a wide range of military operations.

A.1.2 AF Global Logistics Support Center

AFGLSC headquarters is located at Scott Air Force Base. The AFGLSC mission is to deliver integrated global supply chain support for warfighter capabilities.[123] Specific responsibilities for AFGLSC include:

- 140,000 parts managed ($35 billion in inventory)
- Operational liaison between warfighters and suppliers
- 68 weapons systems supported
- 24/7/365 operational spares support
- 32 Area of Responsibility operations

A.2 Sustaining Engineering Tasks

There are (4) Primary Sustaining Engineering Functional Areas:[124]

1. Aircraft Sustainment Directorate Engineers

   Common functions include:

   - Depot and field engineering assistance requests (typically 2-15 day turn time)
   - Integrity programs, corrosion prevention program (typically results in depot requirements)

---

[123] McCoy, G. "The Air Force Global Logistics Support Center: Global Logistics – Warfighter Focus."

[124] Lowas, A. "What is Sustainment Engineering?"

- Configuration management, minor modifications, identification of suitable substitutes
- Supply chain support, especially for Defense Logistics Agency purchases
- Deficiency report investigations, risk analyses, and recommended fleet inspections

2. Commodities Engineers

   Common Functions:

   - Depot engineering assistance requests (typically 2-15 day turn time)
   - Technical expert on contract buy team, contract repair team (build solicitation packages, evaluate proposals, evaluate requests for technical waivers/deviations)
   - Identify suitable substitutes when spare parts (or subcomponents) are not available
   - Deficiency report investigations, risk analyses, and stock actions

3. Depot Industrial Engineers

   Common Functions:

   - Facilities engineering support for any depot-unique facilities
   - Tool and equipment engineering support, including: specification, procurement, maintenance planning (of the tools/equipment), and sometimes complete design
   - Process engineering depends upon maintenance group priorities—some shop layout planning, some end-to-end planning of specialized processes (e.g., paint, plating)

4. Software Maintenance Engineers

   Common Functions:

   - Configuration management, maintenance, and block upgrades of existing software
   - Some include construction/maintenance of system mock-ups for testing
   - Some include limited hardware troubleshooting capability
   - Program management and engineering are typically tightly intertwined

USAF Sustaining Engineering includes all of the following discrete tasks:[125]

Aircraft Structural Integrity Program	Individual Aircraft Tracking
Mechanical Equipment and Subsystems Integrity Program	Fleet-wide Risk Assessment
Avionics Integrity Program	CBM (Condition-Based Maintenance) Assessment
Propulsion Systems Integrity Program	Inspection Interval Specification Based on CBM, RCM, MSG-3
Computer Systems and Software Integrity Program	Computer hardware and software maintenance, upgrades and validation
Corrosion Control	Component Replacement Programs
Part Substitutions	Standard Repair Design
Damage Assessment	Qualification Tests
Individual Item/System Risk Assessment	Quality Assessments
Deferment Decisions	Develop and Monitor Processes
Individual Repair Design	Tool/Equipment Specification/ Design
Trend Discrepancies	Assess Tech Data Sufficiency; Update as Required

Table A-1. USAF Sustaining Engineering Tasks.

Sustaining Engineering tasks also include the following:

- Operational Safety, Suitability, and Effectiveness
  - Systems Engineering Processes
- Sustainment Management
  - Monitoring Performance of Fielded Systems (includes field/depot assistance (i.e., Form 107/202 actions and dispositions), Defense Logistics Agency/AFGLSC assistance, and deficiency reports).
  - Scheduled Maintenance Task Definition
  - Engineering Requirements Review Process
  - Software Maintenance
  - Configuration Management

125 Ibid.

- Modernization Management
    - Modification development/management
    - Configuration Management

All of the tasks defined above are increasing as the various USAF fleets age. Examples of the increased effort to maintain these aircraft are indicated by the increases in field level requests for engineering assistance (Form 107) shown for the A-10 in Figure A-2 below.[126]

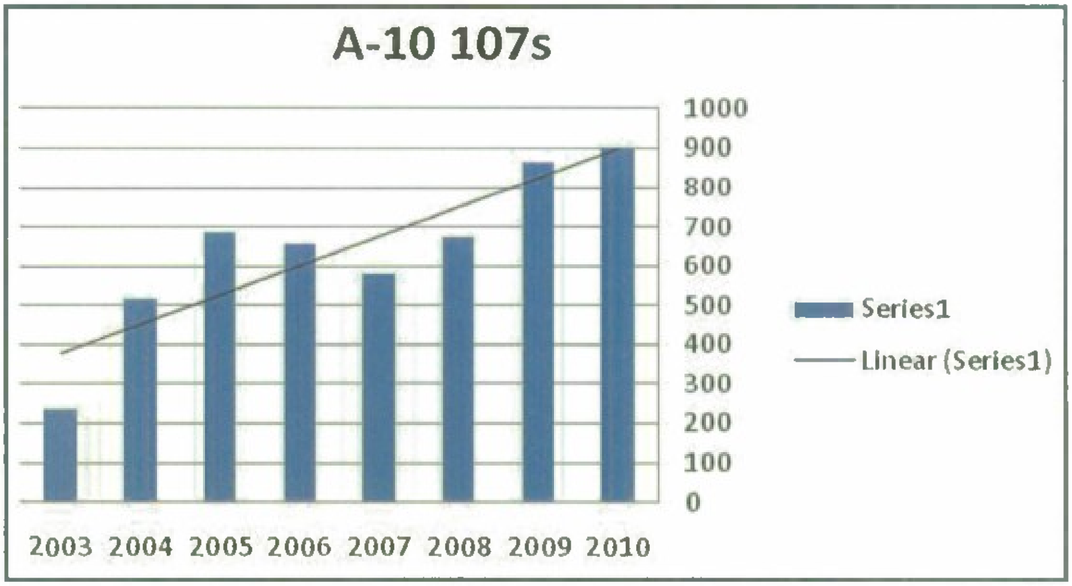


Figure A-2. Field Requests for Depot Engineering Assistance (Form 107s) for A-10 Aircraft 2003-2010.

A comparable example for the A-10 depot maintenance request increases with time is shown in Figure A-3 below.[127]

Sustaining engineering funding is prioritized by the Lead Major Commands and executed by the appropriate System Program Office (SPO). The Lead Commands desire to use their limited modification funding for increased capability instead of maintenance but are willing to use it for capability enhancements that also reduce maintenance whenever such replacements are found. The current workforce is insufficient because aging systems continue to drive increasing workload at the ALCs.

---

[126] Hackett, M. "SAB SAA Panel: Sustaining Engineering Issues."

[127] Ibid.

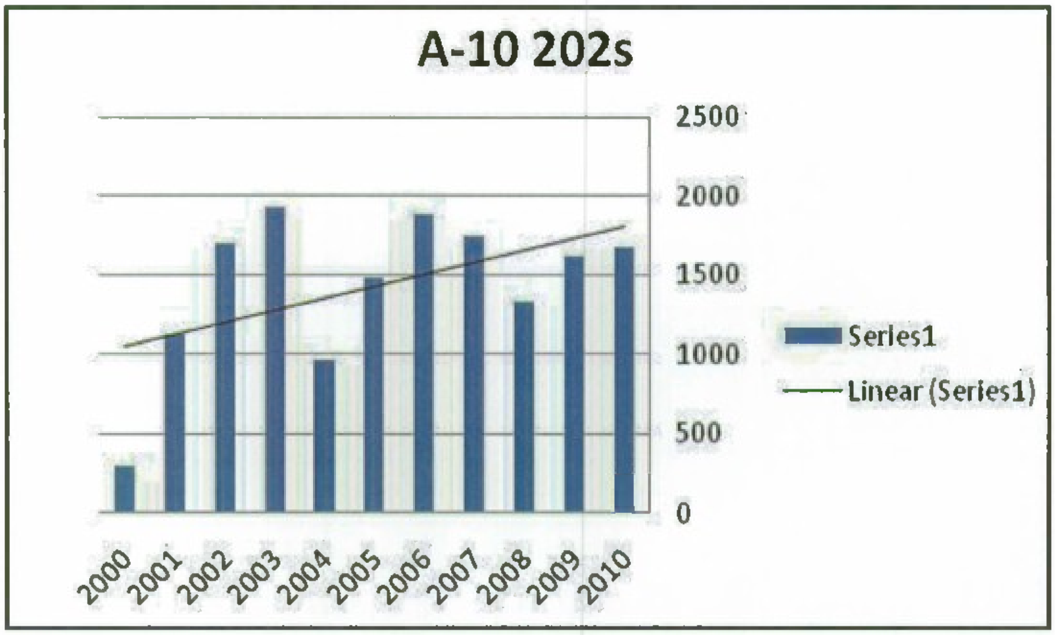


Figure A-3. A-10 Depot Maintenance Requests (Form 202s) versus Time.

A.3 The Integrity Programs

The USAF Integrity Programs (Aircraft Structural (ASIP), Propulsion Systems (PSIP), Mechanical Equipment and Subsystems (MECSIP), Avionics (AVIP), and Computer Systems and Software (CSSIP)) were formed to technically support aircraft airworthiness both in development and for continuing airworthiness in service.[128] They form the "umbrella" under which the USAF fleet can fly safely.

The Integrity Programs are an integral part of airworthiness certification for development programs as well as an integral supporting part of the Fleet Viability Board (FVB) for continuing airworthiness requirements. The Airworthiness Process itself is shown in Figure A-5 below.[129]

The flagship for the Integrity Programs is the Aircraft Structural Integrity Program which was developed to counter significant structural fatigue (and eventually fracture) failures that occurred in the 1950s, when these behaviors were not well understood by the engineering community at large.[130]

The ASIP program established fatigue and fracture mechanics as disciplines within the design community and within military specifications to ensure the durability and damage

[128] White, J. "ASC /EN Opening Remarks: USAF Scientific Advisory Board Sustaining Aging Aircraft Meeting."

[129] Grimsley, F. "USAF Airworthiness Process Overview: Presentation to Scientific Advisory Board."

[130] Babish, C. "USAF ASIP: Protecting Safety for 52+ Years."

tolerance of future USAF aircraft. The fundamental science and engineering steps were followed by adoption into commercial aircraft and implemented by the Federal Aviation Administration (FAA). Since that time, ASIP personnel have been instrumental in reviewing durability and damage tolerance issues and incidents within the Air Force, as well as commercial aviation, to ensure safety in these aircraft. They host an ASIP conference each year to review MDS durability and damage tolerance experience and share best practices and technology advancements in these disciplines. ASIP has tracked the benefits of their efforts over the years since their inception and that is shown in Figure A-4 below.[131]

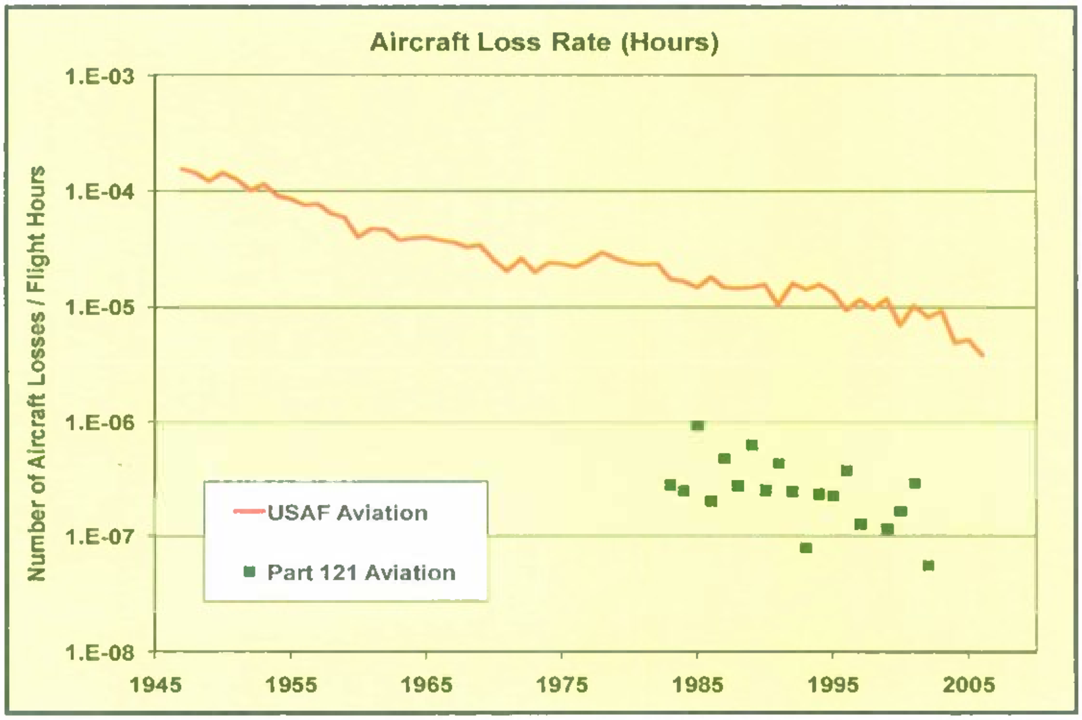


Figure A-4. Historical View of Losses per Flight Hour for USAF Aircraft.

The Propulsion Systems Integrity Program (PSIP)[132] was initiated shortly after ASIP to provide the same level of disciplinary rigor and practice to engine design and sustainment that had been found to benefit structures. Early in the establishment of PSIP, it was found that dynamic fatigue was a driver for wear out and failures in engines and could be monitored by sensing the components of the vibration harmonics of engines. Changes in amplitude of those harmonics could indicate that an engine was suffering wear in a component or part that would eventually cause a failure of that component. Engine health monitoring became a standard

[131] Ibid.

[132] Fecke, T. "Propulsion Integrity Program."

practice for driving maintenance and engine replacement and repair. As these data were analyzed and studied, it became apparent that it would be possible to predict from the detection of these harmonics when failures of the components would occur and the severity of those failures on the health of the engine (whether they would be peripheral or catastrophic to the engine). This paved the way for prognostic health monitoring for engines that is coming into practice for new engines today.

The Mechanical Equipment and Subsystems Integrity Program (MECSIP)[133] is a third step toward ensuring the integrity of aircraft systems. It was begun shortly after ASIP when those benefits were seen, but suffered a lack of strong technical leadership for a decade in which it failed to become as institutionalized as ASIP or PSIP. Through an unfortunate incident involving a T-38 actuator, MECSIP has been reinvigorated, has been brought under the Aeronautical Systems Center's Engineering Directorate auspices, has been asked to hold an annual MECSIP Conference like that of ASIP to share best practices within the community, and has been given a mandate to review the state of the mechanical systems within aircraft in the USAF inventory. The MECSIP community is just starting to understand the kind of data and knowledge base that will be required to design, qualify, and maintain these systems in the future.

Significant MECSIP benefits include:

- Yearly status of subsystem and process health and investment opportunities for early intervention across all platforms
- Subsystem safety and availability accountability
- Tracking and reporting of subsystem Not Mission Capable rate changes by MDS
- Tracking USAF wide subsystem-caused Class A Mishap rate changes
- Inclusion of subsystem considerations in Service Life Extension Programs

Ninety-one percent of Air Mobility Command (AMC) platforms have Military Standard (MIL-STD)-1798 compliant MECSIP Programs. Non-AMC aircraft programs have less mature MECSIP processes than AMC programs, and detailed assessments are proceeding for these (Air Combat Command currently). MECSIP Program status for all major programs is summarized in Table A-2 below:

133 Condron, T. "MECSIP Presentation to Scientific Advisory Board."

MDS	MECSIP Process	Subsystem Health
A-10	Y	G
B-1	G	G
B-2	R	Y
B-52	Y	Y
C-5	G	R
C-17	G	Y
C-130	G	Y
F-15C/D	R	R
F-15E	R	Y
F-16	Y	G
F-22	G	Y
E-3	R	G
E-4	G	G
E-8	Y	G
E-9	G	G
KC-135	G	Y
KC-10	G	Y
MQ-1	R	G
MQ-9	R	R
RC-26B	G	G
RQ-4	R	G
U-2	R	G

Table A-2. MECSIP Program Status for all Major Aircraft Programs.

There is a large effort across all platforms to create Functional Systems Integrated Databases (FSID). The creation and management of these databases is non-uniform as evidenced by the following:

Platform	FSID Created and Managed by
C-130	Mercer Engineering Research Center
C-17	Boeing (Total System Performance Responsibility)
C-5	USAF (Aging Fleet Integrity and Reliability Management)
T-38	Wyle
F-15	Wyle (Eagle Integrity and Reliability Integrated System) – not yet funded
KC-135	USAF (Joint Reliability Availability Management System)
B-1	USAF (B-1 SPO)
A-10	USAF – Tool in Development
F-16	USAF – Tool in Development

Significant areas for improvement in the MECSIP Program are:

- Communication between Line Replaceable Unit Commodity Repair groups and System Program Office (SPO) MECSIP Engineers
- Quality of field maintenance write-ups – Currently reduces MECSIP effectiveness and causes significant additional engineering time to "clean" data. This impedes understanding of problem root causes.
- Component criticality classification and criticality. Disparities exist among programs on numbers of Safety Critical Items.

Additional areas under consideration include:

- Possible integration of AVIP with MECSIP
- Bringing structural aspects of Landing Gear into MECSIP (Currently is in ASIP)

The MECSIP Program recognizes that as USAF aircraft continue to age, certain categories of subsystem equipment will be a challenge:

- Systems that are most prone to deteriorate with age:
    - Wiring
    - Bleed air ducts
    - Hydraulic and fuel lines
    - Brackets/clamps/grommets
    - Elastomers (e.g., fuel bladders and explosion suppression foam)
- Subsystem capacity to meet new requirements
    - Cooling
    - Electric power
    - Wheel/Tire/Brake capacity

The Avionics Integrity Program[134] is the fourth component of the Integrity Programs and deals with avionics components since their lives and failure modes are somewhat different from those of mechanical and hydraulic systems. This area is not following the path outlined by ASIP, PSIP, or MECSIP and thus appears to be less coordinated with the others and more independent. This seems to have occurred despite the successes of the other elements of the Integrity Programs and has contributed, perhaps, to slower acceptance of its processes as a Military Standard. AVIP has not yet developed the standards, data, and knowledge base required to identify failure modes, causes, and conditions that drive lifetimes for their components.

The Computer Systems and Software Integrity Program[135] is the fifth leg of the Integrity Programs and is the newest and least formalized of the programs. Yet, as more functionality is implemented through software than hardware in newer systems, it may be the most important of the Integrity Programs in the future. Thus, it is crucial to accelerate the establishment of CSSIP as a vital and functioning part of the Integrity Programs.

These programs are intended to be an integral part of the USAF process to ensure airworthiness for both aircraft in development and older aircraft. For aircraft in development, the Integrity Program teams review the design and certification test process. For older aircraft they not only review the maintenance status and airworthiness of older aircraft, but determine the requirements to maintain airworthiness for these aircraft as they exceed their design service lives. Thus, their incorporation into the Fleet Viability Board assessments described in the following section should add data driven value into those assessments. Finally it should be noted that these teams review accidents and failure incidents to ensure that solid engineering and science are brought to bear on the solutions proposed for these incidents and that the processes used to return the aircraft to service will ensure safe flight for the remainder of the projected service life of the aircraft.

A.4 Fleet Viability Board

The USAF Fleet Viability Board was formed in 2003 (Figure A-5 below). Its mission is to provide the Secretary of the Air Force (SecAF) and the Air Force Chief of Staff (CSAF) with technical assessments of aging Air Force fleets leading to sustainment or retirement decisions. The FVB has three Survey and Assessment Teams with 53 total authorized personnel. FVB composition includes Senior Board Members (AF Senior Executive Service/Senior Leader level expertise), a Director, Engineering representatives (structures, avionics, propulsion, subsystems), and Senior Board Advisors (Delta Airlines, Federal Express, National Air and Space Administration, Federal Aviation Administration, Naval Air Systems Command, etc).[136]

---

[134] Haley, A. "Avionics Integrity Program (AVIP)."

[135] Springer, D. "Computer Systems and Software Integrity Program (CSSIP)."

[136] Wetzel, J. "Scientific Advisory Board Visit."

A weapon system is defined as viable if "it can do what we need it to do, when we need it to do it, at a price we are willing to pay."[137] This is broken down into the following categories:

- Can it do what we need it to do (technical health)?
- When we need it to do it (availability)?
- At a price we are willing to pay (cost)?

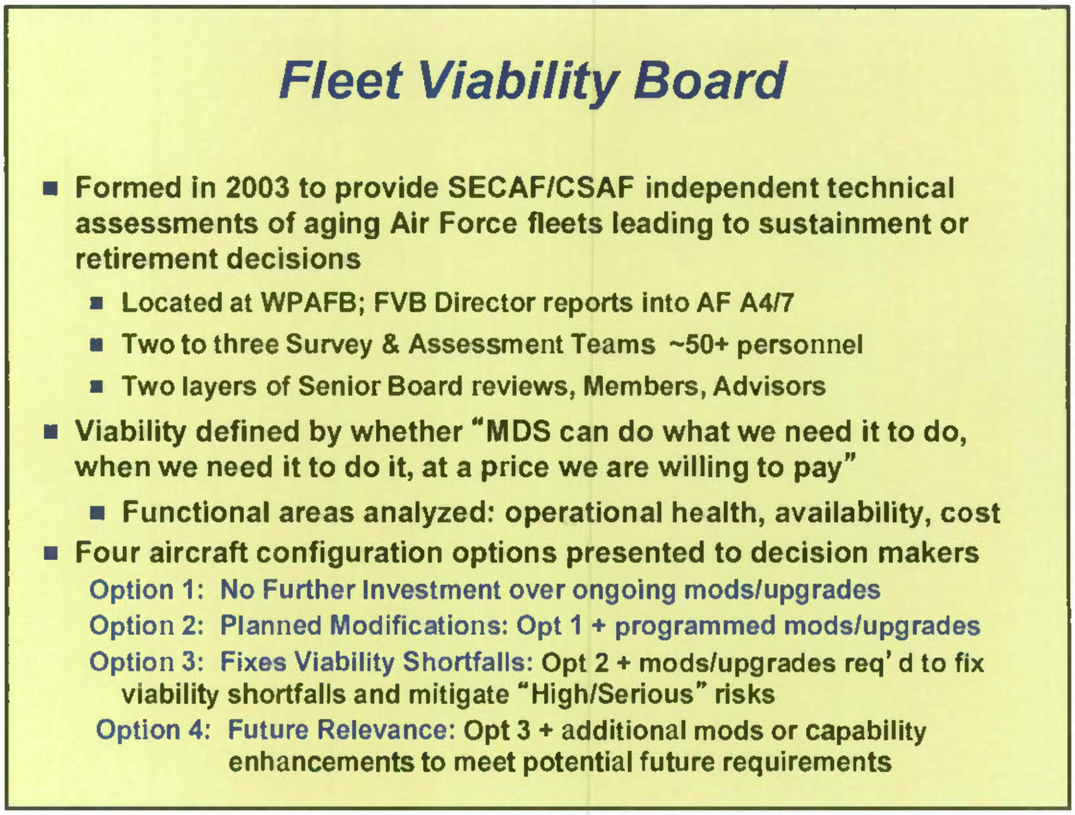


Figure A-5. Air Force Fleet Viability Board.

A typical FVB assessment examines long-term drivers, trends, and issues to project status in three functional areas:

- Operational Health
- Technical fitness to perform mission
- Operational safety

[137] Ibid.

A projection is then made based on the following types of issues: Known (easy); known-unknowns (difficult); unknown-unknowns (near impossible).

The assessment is completed by MDS and covers four snapshot points in time:

- Current year
- 6 years
- 14 years
- 25 years

Four aircraft configuration options are considered:

- Option 1: No Further Investment (Current aircraft configuration with ongoing modifications/upgrades).
- Option 2: Planned Modifications (Option 1 plus planned/programmed modifications/upgrades).
- Option 3: Fixes Viability Shortfalls (Option 2 plus modifications/upgrades required to fix viability shortfalls and mitigate "High/Serious" risks).
- Option 4: Future Relevance (Option 3 plus additional modifications or capability enhancements to meet potential future requirements).

The FVB process provides a thorough evaluation of an MDS. The original Study Terms of Reference requested the Scientific Advisory Board (SAB) Sustaining Aging Aircraft (SAA) Study Panel to evaluate areas that the FVB has already reviewed. Based on the SAB SAA Panel's review of the FVB process and evaluations, it was determined that it would be not be value added for the Panel to study this area further.

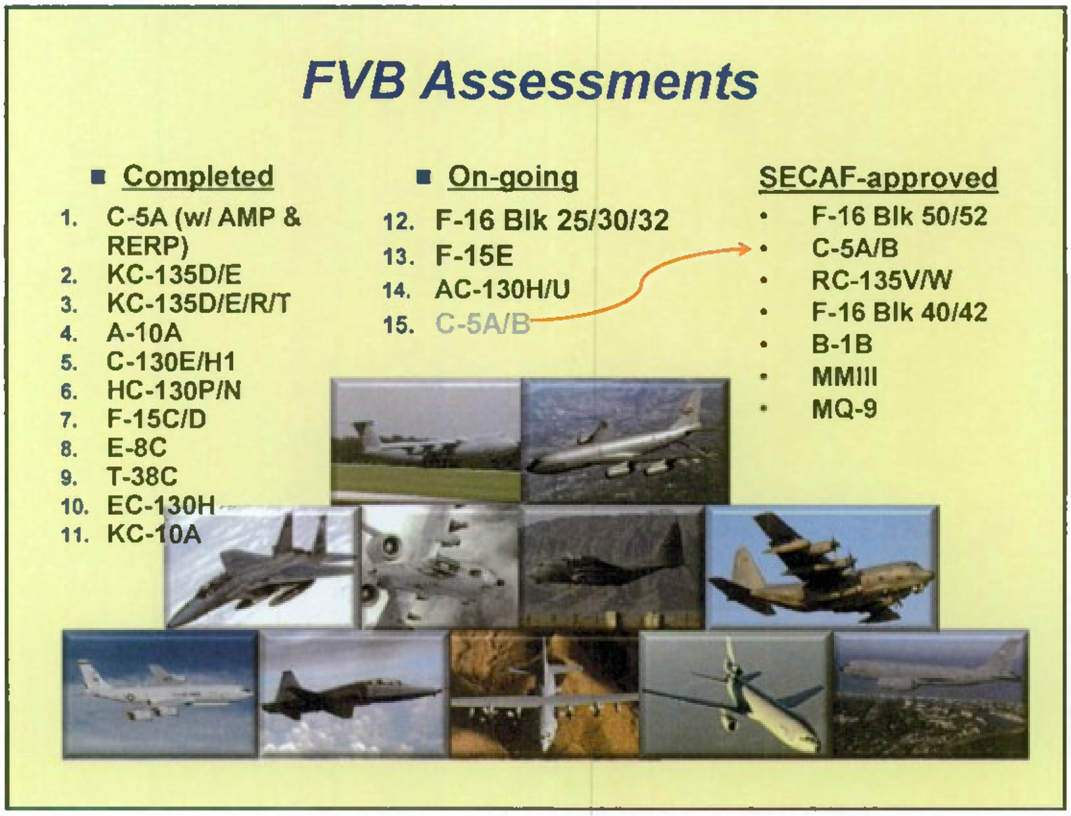


Figure A-6. Fleet Viability Board Assessment Status.

Figure A-6 above documents the FVB completed assessment studies, ongoing studies, and future priorities. The FVB utilizes the following prioritization process to determine which MDSs to examine:

- Fleet Viability Prioritization Model (FVPM) provides rough-order-of-magnitude prioritization based on mathematical analysis of fleets in greatest need of FVB's in-depth assessment
- AF/A8 adjusts priorities based on recapitalization or force planning decision support needs
- "Council of Colonels" finalizes prioritization
- USAF Chief of Staff/Secretary of the Air Force approval

As can be seen from Figure A-6, the FVB has completed many assessments and has several more in process or planned in the future.

A.5 Constraints on the Sustainment Enterprise

During the lifecycle of a Weapon System, the System Program Manager (SPM) will face numerous challenges in sustaining a given MDS aircraft (Figure A-9). The following provides a perspective into the constraints the USAF Sustainment Enterprise typically deals with year in and year out until MDS retirement.

A.5.1 Amount of Money

Identification of aging aircraft solutions must be built into a SPO's budget as early as possible and is reflected in the Weapons Systems Sustainment (WSS) account. WSS encompasses requirements for Sustaining Engineering (SE), Depot Purchased Equipment (DPEM), Contractor Logistics Support (CLS), and Technical Orders (TOs). Projects such as full-scale fatigue tests and durability tests compete against DPEM, CLS, and TO needs. Typically, the Air Force gets about half of what is required for sustaining engineering dollars. Thus, a well-documented requirement and its impact on mission success are critical. For example, in one year, a full-scale fatigue test on the B-1 and C-130 durability tests were funded or "made it above the funding line" while other documented requirements fell "below the funding line" such as B-1 Corrosion Survey Teardown Inspection, F-15E Structural Integrity Program, and T-38 Vertical Stabilizer Teardown. All are valid requirements, but to effectively compete against the ever increasing funding requirements, an accurate and compelling case must be made to key decision leaders to show the impact / benefits.

The Weapon System Sustainment (WSS) program (total force) was funded at about 84% in FY10 and 83% in FY11 and was planned to be 84% in FY12 (subject to actual execution year withholdings/reductions).[138] The sustaining engineering portion of WSS historically has been funded well below 100% with sustaining engineering being funded at about 70% in FY10, 74% in FY11, and 50% in FY12.[139] The increase in SE the last few years has been twofold. First, fatigue tests for the F-15 and B-1 drove the percentage higher. Secondly, the structure of the Air Force Centralized Asset Management (CAM) processes allows an enterprise view of all monies and an established governance structure, which corporately realigns funding to maximize capability. As a result, CAM has been able to fund more sustaining engineering tasks to support the aging Air Force fleet.

The percent funding for all WSS and the sustaining engineering line is not completely indicative of the health of the program. It is more important to look at the actual capability being delivered. In Fiscal Year 2010, the CAM office conducted an intensive requirements deep dive to scrutinize the documented requirements. With respect to the documented sustaining engineering requirements, this review discovered unsubstantiated requirements, placeholder requirements, as well as completed requirements, which had been left in the system. The result was an inflated set of requirements and a misleading picture when reviewing the percent funded. The Headquarters (HQ) Air Force Material Command Deputy Chief of Staff for Logistics (AFMC/A4) is working with the program offices to clean up these items and create a more accurate requirements picture for FY13. This clean up will occur when HQ AFMC/A4 opens the requirements database in July of 2011.

---

138 AFMC/A4L "Centralized Access for Data Exchange (CAFDEx/FRM) Datacall TF 13P Final/13FAC4 dated June 14, 2011 and updated March 5, 2012."

139 Ibid.

A.5.2 Color of Money

The term "Color of Money" is used to describe the differences between appropriated funds. The basics of appropriation law are found predominately in sections of Title 31, United States Code (USC). Any violation of the legal restrictions imposed by Title 31 or other statutes must be reported under provisions of the Department of Defense (DoD) Financial Management Regulations (Specifically, DoD FMR 7000-14, Volume 14), and regulations of the individual Military Services.

When the Congress provides public funds to a federal agency, it also imposes specific limitations on the use of those funds. These restrictions give appropriated funds their "color." The "color of money" is distinguished by purpose, time, and amount. There are five major appropriations:

Appropriation Categories:	Obligation Period:	Appropriation:
Research, Development, Test, and Evaluation (RDT&E)	2 Years	3600
Procurement	3 Years	3010 (Aircraft), 3020 (Missiles), 3080 (Other)
Operations and Maintenance	1 Year	3400
Military Personnel (MILPERS)	1 Year	Various
Military Construction (MILCON)	5 Years	Various

Appropriation Definitions:

- RDT&E: Development of equipment, material, or computer application software; Development Test and Evaluation; Initial Operational Test and Evaluation; and operations costs for some R&D-dedicated installations.
- Procurement: Purchase of major end items and defense systems; initial issue of spares; all costs necessary to deliver a useful end item intended for operational use or inventory; and major modifications to fielded systems.
- Operations and Maintenance: Day-to-day operations; headquarters operations; civilian salaries; travel, fuel, minor construction; training and education; expenses of operational military forces; base operations support; and recruiting.
- MILPERS: Pay and allowances of active duty and reserve military personal; permanent change of station (PCS) moves; training in conjunction with PCS moves; subsistence; bonuses; and retired pay accrual.
- MILCON: Major military construction projects; construction of military schools; construction of facilities; and construction of bases.

The SPM faces many challenges and constraints with the obligation of funding appropriations in avoiding potential violations. Some examples of these challenges and constraints may include:

- Using one account (3400) to fund effort properly chargeable to another account (3600) (Purpose)
- New obligations created against or expenditures made from canceled funds (Time)
- Obligation/expenditures exceeding available funds (may result from upward adjustments, correction of obligations against wrong appropriation/fiscal year, etc.) (Amount)
- Unfunded contract cancellation charges (Amount)
- Directing continued performance without funding (Purpose, Time, Amount)
- Using expired funds to purchase needs chargeable to current appropriation (Time)

A.5.3 Depot Maintenance and Repair

Per Title 10 of the United States Code, Section 2460, the term "depot maintenance and repair" means material maintenance or repair requiring overhaul, upgrading, remanufacturing, or rebuilding of parts, assemblies or sub-assemblies, and the testing and reclamation of equipment, as necessary, regardless of the source of funds for maintenance or repair, or the location at which the maintenance or repair is performed. Two parts of the United States Code, in the areas of Core and 50/50, directly impact where and how much depot maintenance and overhaul will be accomplished.

A.5.4 Core and 50/50

A Department of Defense Instruction[140] identifies statutory requirements that must be met prior to Milestone B. Core Logistics Analysis/Source of Repair Analysis must address Title 10 United States Code Section 2464 (deals with Core) and Title 10 USC Section 2466 (deals with 50/50). All acquisitions undergo Core and 50/50 analysis in the Depot Source of Repair (DSOR) process.

HQ AFMC is responsible for ensuring compliance with Core and 50/50. For Core Logistics Capability, AFMC is governed by Title 10 USC Section 2464 which states that it is essential for the national defense that the Department of Defense maintain a core logistics capability that is Government-owned and Government-operated (including Government personnel and Government-owned and Government-operated equipment and facilities) to ensure a ready and controlled source of technical competence and resources necessary to ensure effective and timely response to a mobilization, national defense contingency situations, and other emergency requirements. Title 10 also states that The Secretary of Defense shall identify the core logistics capabilities) and the workload required to maintain those capabilities.

Core capability must be established no later than 4 years after Initial Operational Capability. All work must be performed by Government personnel, in a Government facility,

---

[140] United States Department of Defense. "Department of Defense Instruction 5000.02: Operation of the Defense Acquisition System."

using Government equipment. Core capabilities are established to support the most demanding combination of contingency phases:

- Readiness: Capabilities required to keep tasked wartime weapon systems ready during peacetime
- Sustainability: Capabilities required to meet wartime surge
- Reconstitution: Capabilities required to return to state of readiness after contingency

The Service Acquisition Executive, or SAF/AQ, has the authority to direct Contractor Logistics Support for major weapon systems such as the F-22 and C-17. Due to system immaturities, CLS was initiated, although the workload had been determined to be an AF core requirement. Later, as the weapons systems matured, Business Case Analyses (BCAs) were conducted to determine the affordability and feasibility of bringing these workloads organic. A BCA decision can be impacted by lack of data rights resulting in a recommendation for a partnership in order to get access to maintenance data. The F-22 program has undergone BCAs for product support and software (all still contract support). A C-17 BCA recommended that the SPO stand-up the F-117 engine at OC-ALC with almost all work still contract support. BCAs can be directed by senior leaders at any time in a program's execution – this can lead to delays in implementation of DSORs and increase program cost through multiple BCAs.

Designation of core workload does not necessarily mean 100% of workload must be performed by organic depots. The agency shall assign sufficient workload to ensure cost efficiency and technical competence in peacetime while preserving the surge capacity and reconstitution capabilities necessary to support fully the strategic and contingency plans. Determining cost effectiveness requires a cost benefit analysis reviewed during the Depot Maintenance Activation Working Group (DMAWG) process

Title 10 USC Section 2466 imposes additional limitations on the performance of depot-level maintenance of materiel and states that not more than 50 percent of the funds made available in a fiscal year to a military department or a Defense Agency for depot-level maintenance and repair workload may be used to contract for the performance by non-Federal Government personnel of such workload for the military department or the Defense Agency. Any such funds that are not used for such a contract, shall be used for the performance of depot-level maintenance and repair workload by employees of the Department of Defense.

The interpretation between Organic and Contractor is defined as follows:

Title 10 USC Section 2466 and guidance from the Office of the Secretary of Defense states that Organic Work is that in which all work is to be performed by government personnel, period. All workload in the ALCs shall be accomplished by government personnel. Organic workload includes government personnel performing work at ALCs under partnerships (Direct Sales/Work-share Agreements), depot field teams, government personnel performing work at Contractor-owned facilities off base from an ALC (i.e., Maintenance, Repair, and Overhaul; Georgia-Robins Aerospace Maintenance Partnership), Government personnel performing work funded by Air Force dollars at other Service depots, and all direct labor, materials, and other factors of production associated with organic workload.

Title 10 USC Section 2466 and OSD guidance states that Contractor Work is that in which all work is performed by contractors with an exception of public-private partnership

workload at Center of Industrial and Technical Excellence (CITE) locations. Contractor workload includes depot maintenance workload performed by contractors under Contract Logistics Support, Interim Contractor Support, DPEM or Materiel Support Division-funded contracts, Contract augmentees at ALCs, Contract field teams, Foreign military depots, Contract personnel performing work at government-owned or leased facilities other than CITE locations, Contract personnel performing Air Force work at other Service depots.

50/50 assessment considers impacts of replacement systems or new capabilities. The Program Managers implement Air Force enterprise core requirements identified in the DSOR. DMAWGs led by the Program Manager make these recommendations. Based on repair generations and costs to stand-up repair capability, if too costly, the System Program Manager will recommend a workload shift to contract support. Activation working groups refine the Program Objective Memorandum (POM) inputs for depot stand-up.

A.5.5 Return on Investment within FYDP

Limited funding within the FYDP often precludes maintenance and upgrade efforts even with a positive return on investment (ROI).

The Weapon System Sustainment efforts are not tied to a return on investment (ROI). Programmed Depot Maintenance (PDM) is based on time with a set interval determined by the Senior Engineer when the Weapon System is required to return to depot for maintenance, modification, or modernization. If the PDM is not conducted, then the aircraft will be grounded resulting in reduced aircraft availability. ROI may be affected by the incorporation of modifications or upgrades to the weapon system. Weapon System modifications and modernization may be driven by safety, risk, and operational impact analysis balanced with a Business Case Analysis (BCA) for the lower risk items. Funding for the PDM is tied to the safety, risks, and operational impacts to the warfighter. In the area of software, the workload is not typically significant for PDM but rather Sustainment Engineering work is based on repairing known discrepancies at the time or required upgrades to keep the system viable. Once again, the same criteria apply and are driven by safety, risk, and operational impact analysis balanced with a BCA for the lower risk items. These efforts are not significantly labor intensive for the PDM cycle but rather for Sustainment Engineering and field level maintenance. Efforts with a significant ROI may not always be incorporated due to higher priority safety risks and operational impacts to the warfighter, prioritized with the available funding budget.

A.5.6 Program Budget Decision (PBD) 720

Under PBD 720 of Fiscal Year 2006, the Air Force realigned its resources to facilitate transforming itself into a more lethal, more agile, streamlined force with an increased emphasis on the warfighter. The offsets and accompanying enhancements implemented were consistent with decisions made during the Quadrennial Defense Review process and supported by the senior leadership of the Department of Defense. These offsets were executed in two broad categories: (1) Organizational and Process Efficiencies and (2) Manpower Reductions. The Air Force streamlined organizations to a smaller, more agile force and transformed its organizational structures with an increased emphasis on supporting the warfighter. PBD 720 reduced military, civilian, and contract dollars to pay for force modernization. AF-wide, active military manpower was cut by over 33,000 positions through FY11. AF Functional Area Managers identified

military manpower bogeys by Air Force Specialty Code. Specifically, within the "blue suit" aircraft maintenance career fields, over 6,600 personnel positions were cut creating a manpower and experience gap in the out years. The field level units were to overcome this cut with processes improvements that have not yet been fully implemented or realized.

A.5.7 Diminishing Manufacturing Sources

The Air Force will continue to fly the current inventory of weapon systems for many more years, longer than the original acquisition plan had projected. Fragile contractor supply bases, profit incentives, and rapid advances in electronic technologies challenge both the organic and contractor repair facilities. The Air Force has seen a dramatic increase in Diminishing Manufacturing Sources and Material Shortages (DMSMS). DMSMS occurs when components and materials are or will become obsolete due to dwindling supply or lack of commercial support to produce the required replacements. The impact of DMSMS can be significant, often causing decreased operational availability and inability to support the Weapon System while being produced, maintained, or repaired.

HQ AFMC is ultimately responsible for setting policy for the acquisition and sustainment of DMSMS. The Air Force and its contactors cannot afford to be in a reactive mode when it comes to managing DMSMS. Waiting until a part becomes unavailable affects repair production efforts and can drive an increase in Mission Impaired Capability Awaiting Parts rate, which ultimately affects Aircraft Availability. Proactively monitoring parts for DMSMS issues, in most cases, allows time to find a replacement part. Suitable replacement parts typically will avoid costly production and sustainment issues avoiding system or component redesigns. DMSMS management is one of the most challenging and costly issues of weapon system sustainment.

To combat this increasingly important issue, the Air Force Global Logistics Support Center uses predictive DMSMS tools in daily supply chain executions to provide the Air Force with an automated means of monitoring parts on a near "real time" basis and predicting obsolescence. The Advanced Component Obsolescence Management (AVCOM) predictive tool was initially developed in 1989-90 by BAE Systems to support DMSMS challenges. Since its inception, both the USAF and BAE have funded specific AVCOM enhancements to insure the tool meets the proactive DMSMS management needs of the Air Force. Over 4,700 USAF systems have been loaded in AVCOM in the past 10 years. AVCOM is a fully integrated DMSMS resolution toolset which automates the complex analyses and computations required to support proactive DMSMS. Organic and contractor users depend on the AVCOM tool to provide a means to identify and resolve many obsolete part issues. AVCOM is typically accessed over three thousand times a month and automatically assesses and prioritizes the obsolete components of a system based on when they will impact the ability to repair the next higher assembly. AVCOM allows users to prioritize problems, establish resolution timelines, POM for required funding, and ultimately focus on the typically small subset of obsolescence problems that pose a near-term threat to Weapon System sustainment.

A.5.8 Data Rights

Technical data rights are a key enabler in the lifecycle of a Weapon System. United States Law (Title 10 USC Section 2320) and DoD policy (DoD Instruction 5000.02) require the Air Force to consider securing data rights during weapon system acquisitions to enable the Air

Force to organically support these weapon systems throughout the lifecycle. Most System Program Managers do not adequately address technical data rights in the acquisition phases. This causes follow-on challenges to Weapon System performance. Some of those challenges are delays and cost growth, data rights costs, and with limited funding, impacts on sustainment strategies. When acquisition is no longer competitive, product data rights cost becomes either very expensive or often unavailable. Most acquisition programs typically initiate CLS due to the Weapon System ongoing development, immature design, and lack of finalized product technical data. This creates significant issues when the Air Force transitions from a CLS approach to an Organic Sustainment approach. Contractors' interest in data rights control typically is based on protecting the investments made by the company and the lucrative aftermarket work such as spare parts, repairs, modifications, and upgrades to sustain viability of the Weapon System. To maintain all options throughout a Weapon System lifecycle, the Air Force should acquire product technical data or the options to procure technical data at the onset of the Acquisition Lifecycle Phase while competition still exists.

A.5.9 Time and Material Contracts

Time and Material (T&M) contracts provide an avenue for acquiring supplies and/or services on the basis of direct hours at a specified fixed hourly rate and/or materials at a cost including material handling costs if appropriate. T&M Contracts are typically used when it is not possible to estimate the anticipated work, costs, and schedule with a high degree of confidence. T&M is a viable contracting approach in the areas of sustainment when a solution to an issue/repair is not clearly known and the Air Force may want to pay a contractor by the hour at a negotiated rate with a limit on how much to spend to find out what is wrong and fix it. An established T&M requirement typically allows work to initiate almost immediately through the Contracting Officer (CO). The CO must establish that it is not suitable to acquire the service using any other contract method arrangement and document their findings in a written determination and findings. The CO must establish that one of the other contracting approaches such as firm-fixed-price or fixed price with incentive award fee is not timely or cost effective. Although T&M Contracts may allow for rapid execution and assistance in the Sustainment Phase, the T&M approach is not the preferred Air Force approach as risks and performance are shifted to the Contractor using other contracting approaches.

(This Page Intentionally Left Blank)

Appendix B: Terms of Reference

USAF Scientific Advisory Board

Sustaining Air Force Aging Aircraft into the 21st Century

Background

The Air Force will operate its legacy aircraft for decades beyond their originally projected service lives, stressing structures, engines, and other aircraft systems. The Fleet Viability Board (FVB) was formed to assess the technical fitness and the associated availability and cost of continued ownership of Air Force weapon systems. While the Board projects the fitness of all fleet systems (e.g., structures, propulsion, avionics, offensive/defensive, and electro-mechanical subsystems), structures, and propulsion are analyzed at the greatest depth. Addressing structures and engines is a complex task, but other aircraft systems can also be life limiting; pose flight safety risks; and affect aircraft availability, effectiveness, and Operations and Maintenance (O&M) costs. Investments in appropriate modifications/replacements are planned for some aircraft fleets, but deferred for others. For example, the FVB has identified service life issues associated with the landing gear of the A-10, T-38, and F-15 fleets. Some of these fleets have scheduled depot maintenance for their landing gear or plans to replace existing landing gear with new hardware, but others are deferring these investments. There is a need to help the Air Force identify and prioritize investments in other aircraft systems while identifying how such investments can establish a foundation for future adaptations and performance enhancements.

Charter

The study will work closely with the FVB to:

- Identify specific aircraft systems, besides structures and engines that contribute to safety, availability, and effectiveness for aging aircraft.
- Using the FVB's prioritized list of aircraft, determine for all fleets the maintenance status of these aircraft systems, and rank them in terms of priority due to risk across Mission Design Series (MDS).
- Examine commercial practices in airlines, air freight services, and other industries, and evaluate how they can be applied to meet Air Force needs.
- Assess the time and first-order investment required to complete needed modifications of the high priority aircraft systems, and the resulting effect on operational availability of the fleets. Perform a first-order assessment of O&M cost savings and avoidance and military utility of improved capabilities that would result.
- Recommend how the Air Force should proceed to address these modifications by MDS in priority due to mission risk, operational availability, O&M cost.

- Identify technology needs and technology approaches that can be applied or developed to extend life or ease maintenance of these aircraft systems, while facilitating future adaptations and performances enhancements of the aircraft.

Study Products

Briefing to SAF/OS & AF/CC in July 2011. Publish report in December 2011.

Appendix C: Study Members

Study Leadership

Study Chair: Dr. Alan C. Eckbreth
Study Vice Chair: Mr. Charles R. Saff

General Officer Participant

General Officer Participant: Major General Kathleen D. Close, USAF, AFMC/A4
General Officer Participant Representative: Mr. James J. Yankel, DAF, AFMC/A4

Members

Mr. Kevin P. Connolly
Mrs. Natalie W. Crawford
Dr. Chris D. Eick
Professor Mark S. Goorsky
Mr. Neil G. Kacena
Professor David W. Miller
Dr. Robert E. Schafrik
Dr. Douglas C. Schmidt
Professor Daniel L. Stein
Professor Michael A. Stroscio
Professor Gregory Washington
Dr. John C. Zolper

Government Participants

Mr. Daniel J. Brewer, AFRL/RX

Study Support

Lieutenant Colonel Keith J. Hill, USAFR
Lieutenant Colonel Anne E.C. Johnson, USAFR
Major Armando Deleon, Jr., USAF
Major Harris J. Hall, USAFR
Major Brandon J. Lingle, USAF
Major Valerie M. Manning, USAFR
Major Dennis W. Woodfork, USAFR
Captain Jonathan M. Davis, USAF
Captain Paul W. Tinker, USAF
Mr. William M. Quinn

(This Page Intentionally Left Blank)

Appendix D: Study Meetings and Briefings

Overviews/Perspectives

Mr. Blaise Durante, SAF/AQX
Dr. Jean Gebman, RAND
Lt Gen Michael E. Zettler, USAF (Ret)

HQ Air Force

SAF/FMC
AF/A4L
AF/A5R
AF/A8X/A8P
AF/A9
AF/CVR

USAF Major Commands

Air Combat Command A4/A5/A8/ST
Air Mobility Command
Air Education and Training Command A4/7
Air Force Global Strike Command
Air Force Materiel Command A4
Air Force Special Operations Command A4/7

Other Air Force

1st Fighter Wing
388th Fighter Wing
Aeronautical Systems Center
AF Global Logistics Support Center
AF Office of Scientific Research
AF Research Laboratory/RX/RZ/RB
Ogden Air Logistics Center
Oklahoma City Air Logistics Center
Warner Robins Air Logistics center
USAF Fleet Viability Board (AF/A4L-FVB)

Other DoD

Office of Naval Research
Naval Air Systems Command

Industry

Boeing
Delta Air Lines
General Atomics
Lockheed Martin
Northrop Grumman

Other Government/Federally Funded Research and Development Centers

Federal Aviation Administration
National Aeronautics and Space Administration
RAND Corporation

(This Page Intentionally Left Blank)

Appendix E: Glossary

The terms and associated definitions used herein were derived from various sources and reflect the collective judgment of the Air Force Scientific Advisory Board Sustaining Aging Aircraft Study Panel as what would appropriately reflect the intended meaning of the term within the context of this Study Final Report.

4th Generation Fighters – Aircraft in service approximately from 1980 onward, representing the design concepts of the 1970s. Representative fighters include the "teen" series of American fighters (e.g., F-14, F-15, F-16, and F-18).

50/50 Rule – A nickname for a federal law (Section 2466 of Title 10 of the United States Code) that requires that no more than 50 percent of depot maintenance funds provided to a military service or defense agency can be expended for private sector work.

5th Generation Fighters – Fighter aircraft that are characterized by being designed from the start to operate in a network-centric combat environment and to feature extremely low, all-aspect, multi-spectral signatures employing advanced materials and shaping techniques. Typically they are equipped with multifunction, active electronically scanned array radars with high-bandwidth, low-probability of intercept data transmission capabilities. Two examples include the F-22 and the F-35. This generation of fighters tends to be extremely capable and very expensive (both to acquire and operate/maintain). See entries for the F-22 and F-35.

A-10 Thunderbolt II – A United States Air Force (USAF) twin jet attack aircraft developed by Fairchild-Republic Company in the 1970s. Its primary mission is to provide close air support. The A-10 has a large amount of armor to protect the pilot and vital aircraft systems and was designed around a large 30 millimeter automatic cannon which forms the primary armament of the aircraft. A-10s have been upgraded with new avionics and many are also receiving a new wing. The USAF currently flies over 300 A-10 aircraft.

Active Electronically Scanned Array (AESA) – A type of phased array radar whose transmitter and receiver functions are composed of numerous small solid-state transmit/receive modules. US aircraft employing AESA radars include the F-22, the F-35, and later versions of the F-16, F-15, and the F-18.

Aging Aircraft – The USAF has a total inventory of aircraft whose average age is approximately 25 years. An "aging aircraft" is one whose age exceeds 20-25 years or which (if younger) has exceeded 75% of its certified service life. Significant (fleet size and/or capability) examples of USAF aging aircraft types include the F-16A-D, F-15A-D, B-52H, B-1B, A-10, KC-135, KC-10, C-5, and T-38.

Air Logistics Center (ALC) – An Air Force Materiel Command (AFMC) depot that performs sustainment and depot-level complex maintenance on a number of weapons systems or

families of components (e.g., engines, electronic warfare equipment, or landing gear). The USAF currently has three major ALCs located at Hill Air Force Base (AFB) Utah, Tinker AFB Oklahoma, and Robins AFB Georgia. See depot entry.

Aircraft Availability – A metric used by the USAF to indicate the "health of the inventory." It is requirements based and for a given aircraft type (e.g., such as the C-130H, B-1B, C-5A, or the F-15E) is defined as the total number of Mission Capable hours divided by the Total Aircraft Inventory (TAI) hours, where TAI is defined as the sum of all Primary Aircraft Assigned hours, Backup Aircraft Inventory hours, and Attrition Reserve hours (i.e., the potential hours available for the entire aircraft type fleet).

Aircraft and Missile Logistics Requirements Determination Process – This process identifies and prioritizes requirements needed to achieve weapon system availability/capability targets required by the warfighter. Each weapons system is assigned to a Lead Command that performs this process for that system. AFMC is lead command for requirements that are not tied to a specific weapon system.

Aircraft Structural Integrity Program (ASIP) – A series of time-phased actions, procedures, analyses, tests, etc., intended to provide reliable, affordable, and supportable flight vehicle primary and secondary structures, thus contributing to the enhancement of total systems mission effectiveness and operational suitability while minimizing cost and schedule risks. An ASIP is normally developed and tailored for each Mission Design Series of aircraft (manned or unmanned) the Air Force acquires, uses, or leases.

Air Force Total Ownership Cost (AFTOC) – A management information system/data warehouse that provides visibility into the life cycle costs of all major weapons systems through all appropriations and USAF Major Commands. AFTOC includes historical and near real time cost data. It was designed to significantly reduce the need for analysts and DoD staff to acquire, normalize, aggregate, allocate, and organize financial and logistic data on Air Force systems and infrastructure and to provide analytical capability that would otherwise not exist.

Airworthiness – Fitness for flight operations, in all possible environments and foreseeable circumstances for which aircraft or device has been designed.

Airworthiness Certification Authority – A designated competent entity that determines that an aircraft or device is fit for flight operations, in all possible environments and foreseeable circumstances for which it has been designed.

Annual Planning and Programming Guidance (APPG) – A USAF planning document produced by AF/A8 that uses as inputs guidance from the Secretary of Defense, Secretary of the Air Force, and the USAF Strategic Plan. The APPG defines the USAF's corporate position regarding readiness and sustainability, force structure, infrastructure, and modernization needs. The outputs of the APPG are used by the Major Commands to build their inputs to the annual Program Objective Memorandum which (among many other matters) sets the resource levels for activities within the Air Force Logistics Enterprise.

Application Specific Integrated Circuits (ASIC) – An integrated circuit customized for a particular use, rather than intended for general-purpose use. In general ASICs are

optimized for a particular application and are therefore quicker/more efficient at performing that task than a general purpose microchip would be (however, they are also likely to be more expensive and take longer to develop).

Area of Responsibility (AOR) – A pre-defined geographic region assigned to a Combatant Commander that are used to define an area with specific geographic boundaries where they have the authority to plan and conduct operations; or for which a force, or component commander bears a certain responsibility.

Automated Budget Interactive Data Environment System (ABIDES) – The budget system currently in use by the Air Force. It has been in use since 1960s and houses many modules including the Classified/Unclassified Accounting System and the Financial and Force Planning. ABIDES is recognized as the official Air Force position with respect to the Department of Defense (DoD) Planning, Programming, and Budget Execution (PPBE) system.

AVCOM Tool – The Advanced Component Obsolescence Management tool is a BAE Systems developed web-based readiness and sustainment software tool which allows users to track and plan for the replacement, upgrading, inventory location, and ordering of new parts. The Air Force logistics enterprise relies heavily on this tool, which has a database containing 15 million parts and access to information on an additional 50 million parts. It is the primary tool within the USAF for management of diminished manufacturing sources issues and is also used by other military services and within industry.

Avionics – All of the electronics systems contained in an aircraft.

Avionics Integrity Program (AVIP) – A process through which the design allowables, manufacturing, and process controls for the aircraft electronics equipment are established and demonstrated to meet functional and life performance requirements. AVIP defines life, usage, environment, and supportability requirements and process tasks to achieve required performance over the life of the electronics. AVIP employs basic physics, chemistry, and engineering principles to ensure an understanding of the influences of the usage and environments on materials and parts. AVIP also focuses on key product and process characteristics and control of variability of materials, parts, and processes.

B-1B Lancer – The Boeing B-1B Lancer is a long range variable-sweep wing bomber used by the USAF. It has four turbofan engines and employs a blended wing-body design to achieve a maximum speed of about Mach 1.25 and is optimized for low level penetration. It can carry the largest payload of both guided and unguided weapons of any aircraft in the USAF inventory. The B-1B has a normal aircrew of four and is currently used only in a non-nuclear role.

B-2A Spirit – The B-2A is a long range multi-role bomber flown by the USAF. It is capable of delivering both conventional and nuclear munitions. Its low-observable, or "stealth," characteristics give it the ability to penetrate sophisticated defenses and threaten heavily defended targets. The B-2's low observability is derived from a combination of reduced infrared, acoustic, electromagnetic, visual, and radar signatures.

Backup Aircraft Inventory (BAI) – A quantity of aircraft above the Primary Aircraft Inventory (PAI) whose purpose is to permit scheduled and unscheduled maintenance,

modifications, inspections, and repair without reduction to the number of aircraft required to be available for operational missions. See entry for PAI.

Brochure – For a given aircraft type undergoing depot-level maintenance, repair, and overhaul, the proposed/planned tasks are compiled in a document called a "brochure." The brochure includes tasks, approved hours, occurrence factors, and number of aircraft scheduled to work per year by mission design series. It also includes a narrative describing the support provided and its cost by task.

Business Case Analysis (BCA) – A process that develops and a resulting set of documents that lays out the reasoning for initiating a project or task. A business case normally captures both the quantifiable and unquantifiable characteristics of a proposed project. These characteristics can include performance, producibility, reliability, maintainability, and supportability enhancements. A BCA is used to (1) guide the initial decision to invest in a project, (2) guide the decision to select among alternative approaches, and (3) validate any proposed scope, schedule, or budget changes during the course of the project.

C-130 Hercules – A four-engine turboprop tactical airlift military transport aircraft built by Lockheed and operated by the USAF and US Navy and over 60 other countries' military services. Variants of the C-130 have been used for aerial refueling, gunship, weather reconnaissance, and many other missions. There have been over 40 different models and variants. The USAF accepted its first C-130 in 1956 and the aircraft (much upgraded) is still in production for the US military and other countries. The USAF operates the 1960s model C-130E (all have been or are being retired from service) and C-130H models (many earlier H-models are being or have been retired) and well as the C-130J Super Hercules. Over 400 C-130s remain in the USAF inventory; however this number is being reduced as earlier production models are being retired from service, many of which will not be replaced by C-130Js. The current in-production model is the C-130J, which has upgraded engines, avionics, and operational/logistics performance, and is operated with a reduced crew.

C-17 Globemaster III – A Boeing four-engine airlift aircraft operated by the USAF and several other air forces around the world. It is used for both strategic and tactical airlift of troops and cargo. It can carry up to 171,000 pounds of cargo and is air-refuelable. About 213 C-17s are currently in service with the USAF.

C-5 Galaxy – The C-5 Galaxy is a very large four-engine jet transport aircraft built by Lockheed and has been operated by the USAF since 1969. It provides a long range strategic airlift capability (payloads up to 270,000 pounds) and includes the ability to carry outsize and oversize cargos, including all air-certifiable cargo. The C-5 can be refueled in flight. Most of the original 81 C-5A models have been or will be retired from service by 2013. About 52 C-5M "Super Galaxy" aircraft will remain in the USAF force structure. These aircraft are mainly C-5Bs that have been upgraded with new engines, avionics, and a variety of structural and systems reliability improvements.

Carbon Nanotube – A form of carbon with a nanostructure that can have a length-to-diameter ratio greater than one million. These cylindrical carbon molecules have novel properties that make them potentially useful in many applications. They exhibit extraordinary strength and unique electrical properties, and are very efficient conductors of heat. Their

name is derived from their size, since the diameter of a nanotube is on the order of a few nanometers.

Centralized Asset Management (CAM) – In 2006, the CSAF directed the sustainment community to "radically simplify and streamline AF sustainment business practices." The result was to focus resources on AF priorities, as defined by the Air Force Corporate Structure, and as a result, the CAM office was developed. The mission of the CAM office is to centralize and integrate management of AF sustainment to optimize warfighting capability through effective and efficient allocation of resources across the enterprise. The CAM office guides the Weapon Systems Sustainment PPBE Process through a well-defined, inclusive governance process.

Charge Coupled Device (CCD) Detector – A charge-coupled device (CCD) is a semiconductor chip, one face of which is sensitive to light and then takes an electrical charge resulting from that light and moves the charge to an area where the charge can be converted into a digital value (and hence processed and/or amplified). A CCD-based detector (or sensor) uses CCDs to provide its images. A CCD-based detector contrasts with a device using photographic or photoelectric devices. CCD devices are common in the field of digital imaging.

Chief Technology Officer (CTO) – A suggested position to be established at each USAF Air Logistics Center. The CTO's role would be to align the sustainment technology vision with the ALC's operational and business strategies by integrating ALC processes with the appropriate technologies. The CTO would also be responsible for all aspects of overseeing the development of requirements for new sustainment technologies, advocating them within the AFMC process to be prioritized for implementation action by the AF Research Laboratory, and the evaluation, acquisition, and adaptation as required of current sustainment technologies within the ALC. The CTO would report to the ALC Commander/Director.

Coefficient of Determination – A statistical method that explains how much of the variability of a factor can be caused or explained by its relationship to another factor. Coefficient of determination is used in trend analysis. It is computed as a value between zero and one and the higher the value, the better the fit. The coefficient of determination is an important tool in determining the degree of linear-correlation of variables ("goodness of fit") in regression analysis. It is also referred to as "R-Squared" or R^2.

Color of Money – United States law provides that "Appropriations shall be applied only to the objects for which the appropriations were made except as otherwise provided by law." The annual DoD appropriations acts include approximately 100 different appropriations which, colloquially, are known as "color of money." Major "colors" include funds for operations and maintenance (O&M), research and development (R&D), procurement (divided into aircraft, missile, and other), Military Personnel, and Military Construction. Each major category has overall limits on the time period in which the funds may be obligated and expended along with many other restrictions, and there are many sub-categories ("hues") each with their own restrictions and limits within each major appropriation. "Color of money" may refer to the overall appropriation or to specific levels of subcategories in each, depending on user and context.

Commercial Off the Shelf (COTS) – Software or hardware, technology, or other products that are ready-made and available for sale, lease, or license to the general public. COTS items require no unique government modifications or maintenance over the life cycle of the product to meet the needs of the procuring agency. Motivations for using COTS components include reduction of overall system development and costs. There are sometimes maintenance cost advantages to using COTS equipment, but since the lifecycle of COTS systems are determined by public desire, they can be subject to availability issues after some period of time.

Comprehensive Engine Management System – USAF's standard data system for tracking engine status, accountability, and critical parts life tracking. It provides on-line real-time data accessibility to all levels of management and supports engine accountability and critical parts life tracking requirements. CEMS supports both the On-Condition Maintenance and Reliability Centered Maintenance concepts for engines.

Compton Scattering – A type of scattering that X-rays and gamma rays (both photons with different energy ranges) undergo in matter. The inelastic scattering of photons in matter results in a decrease in energy (increase in wavelength) of an X-ray or gamma ray photon, called the Compton Effect. Part of the energy of the X/gamma ray is transferred to a scattering electron, which recoils and is ejected from its atom (which becomes ionized), and the rest of the energy is taken by the scattered, "degraded" photon.

Computer Systems and Software Integrity Program (CSSIP) – A development and test process intended to ensure integrity is designed into aircraft computer systems and software (whether the aircraft is new, a legacy version being upgraded with new capabilities, or an existing embedded system being maintained). CSSIP addresses the entire weapons system computer system architecture from a Systems Engineering perspective throughout all phases of acquisition and sustainment and is intended to comprehensively address software, hardware, computer system architectures, and system functional integration to assure airworthiness and mission effectiveness of the system.

Condition Based Maintenance (CBM) – A set of maintenance processes and capabilities derived in large part from real-time assessment of weapon system condition using data obtained from embedded sensors and/or external tests and measurements using portable equipment. The goal of CBM is to perform maintenance only after one or more indicators show that equipment is going to fail or that equipment performance is deteriorating.

Contract Logistics Support – The performance of maintenance and/or materiel management functions for a DoD system by a commercial activity. This support may be contracted on a long- or short-term basis.

Core Automated Maintenance System (CAMS) for Airlift (GO81) – Provides both a maintenance management system and a logistics command and control system for the USAF mobility aircraft fleet. CAMS provides fleet-wide visibility of status and location of aircraft, discrepancy history, time-compliance technical order status, etc. It also provides Air Mobility Command weapon system managers and analysis personnel with fleet wide information for overall management of the weapon systems and can also determine historical trends.

Core, Core Depot Maintenance – A set of government organic logistics capabilities mandated by law (US Code). The Department of Defense must maintain a core logistics capability that is Government-owned and Government-operated (including Government personnel and Government-owned and Government-operated equipment and facilities) to ensure a ready and controlled source of technical competence and resources necessary to ensure effective and timely response to a mobilization, national defense contingency situations, and other emergency requirements. Note: See 50/50.

Corrosion – The reaction of an engineered material due to chemical reactions with its surroundings. In the most common use of the word, this means electrochemical oxidation of metals in reaction with an oxidant. Many structural alloys corrode merely from exposure to moisture and air. Corrosion is most often determined by its byproducts: rust, flaking, or oxidation buildup on the surfaces of metallic parts. Corrosion can be concentrated locally to form a pit or crack, or it can extend across a wide area more or less uniformly corroding the surface. While not referred to as corrosion, resins and sealants also react with moisture, temperature, ultraviolet radiation, and air and these can degrade their performance as well.

Cost Driver – An activity that is the root cause of why a cost occurs. Often it is a term used to relate the cause of an increased cost or to describe an increasing cost trend.

Critical Safety Item (CSI) – A part, assembly, installation, or production system with one or more essential characteristics that, if not conforming to the design data or quality requirements, would result in an unsafe condition that could cause loss or serious damage to the end item or major components, loss of control, or serious injury to personnel.

D200 Requirements Management System (D200RMS) – A part of the Air Force Materiel Command's Requirements Management System suite of systems, D200RMS encompasses the automated and manual functions involved in the AFMC's Materiel Requirements Process. This process forecasts and controls procurement and repair requirements of materiel needed for logistics support of weapons systems operated by the Air Force.

Demand Forecast Accuracy – Demand forecasting is the activity of estimating the quantity of a product or service that will be required. Demand forecasting involves techniques including both informal methods, such as educated guesses, and quantitative methods, such as the use of historical sales data or current data from test markets. Forecast accuracy is a measure of how close the actual demand was/is to the forecasted quantity. Accuracy is the converse of demand forecast error and normally the error is calculated via the mean absolute percentage error method.

Depot – Pronounced dep' o. A facility dedicated to logistical (systems maintenance or storage of supplies) operations. A depot provides on- and off-equipment maintenance tasks requiring highly specialized skills, sophisticated shop equipment, and/or special activities of a supporting command at a logistics center, centralized repair facility, contractor repair facility, or, in some cases, at an operating location.

Depot Level Repairable – A part, system, or subsystem whose repair is controlled by or accomplished by one of the USAF depots. Only the depot can make the determination to condemn/scrap a depot-level repairable item.

Depot Maintenance Action Working Group – A group of representatives from the activities involved in activating a depot maintenance capability for individual systems and equipment.

Depot Purchased Equipment Maintenance – Covers organic and contract depot level maintenance/overhaul for aircraft, engines, missiles, software, and other major end items (e.g., radios, tool sets, vehicles, radars, and other major pieces of equipment that are assembled and ready for intended use).

Depot Source of Repair – A decision process undertaken for all programs that defines where depot-level repairs will be accomplished (organic depot vs contractor facility and, if organic, whether another Service may have existing depot capacity that could accomplish the task more economically than retaining it within the Air Force organic depot enterprise). The objective of the process is to reduce weapon system costs for depot activation and recurring depot support.

Design Service Life – The design service life is the period of time (e.g., years, flight cycles, hours, landings, etc.) established at the time of the system's design, during which the structure is expected to maintain its structural integrity when flown to the design loads / environment spectrum.

Determination and Finding (D&F) – A special form of written approval by an authorized official that is required by statute or regulation as a prerequisite to taking certain contract actions. The "determination" is a conclusion or decision supported by the "findings." The findings are statements of fact or rationale essential to support the determination and must cover each requirement of the statute or regulation. A D&F shall ordinarily be for an individual contract action however, unless otherwise prohibited, D&Fs may be executed for classes of contract actions.

Development System Manager – The individual with functional responsibility for the development portion of a system's life cycle and in support of a program manager.

Diminishing Manufacturing Sources (DMS) and Material Shortages (DMSMS) – The loss or impending loss of manufacturers or suppliers of items or raw materials. DMSMS is a concern whenever a system is no longer in production, since loss in revenue can be a cause for a supplier to shut down. Diminishing supplier base can be an issue even before production is complete in an era of diminishing system acquisition.

DoD Acquisition Milestones (A, B, and C) – The management framework for defense systems acquisition is commonly referred to as the acquisition life cycle. The life cycle process consists of phases separated by decision points called milestones. Milestones (MS) established by Department of Defense Instruction 5000.02 are:

- **MS A** approves entry into the Technology Development phase,
- **MS B** approves entry into the Engineering and Manufacturing Development phase (Note: formal program initiation normally occurs at MS B), and
- **MS C** approves entry into the Production and Deployment phase.

E-3 Sentry – A modified Boeing 707 airframe configured with an airborne warning and control system flown by the USAF, North Atlantic Treaty Organization, and the armed forces of several other countries. The E-3 provides an integrated command and control battle

management surveillance, target detection, and tracking capability. Initial operational capability for the USAF occurred in 1978 and the USAF 33 E-3's mission systems have been updated on a regular basis since then. The USAF currently has about 33 E-3 aircraft in its inventory.

Economic Service Life – The remaining useful life of an asset that results in an acceptable annual equivalent cost. The economic life is not necessarily equal to the asset's useful service life. As an asset ages and operating and maintenance costs increase, it may be more economical to replace the asset before the end of its service life instead of incurring the increased operations and maintenance costs near the end of the service life.

eLog21 – Expeditionary Logistics for the 21st Century is an umbrella strategy that integrates and governs logistics transformation initiatives to ensure the warfighter receives the right support at the right place and the right time. The eLog21 effort promotes data sharing, collaboration, and better decision making across the entire Air Force supply chain. The overall goals of eLog21 are to increase equipment availability and reduce operations and support cost. Benefits of eLog21 are expected to include increased data accuracy, optimized repair planning, centralized asset management, total asset visibility, resource optimization, and helping to improve/enable predictive maintenance.

Engineering Requirements Review Process (ERRP) – The process through which the initial Programmed Depot Maintenance work task definition is done. The ERRP develops requirements for each MDS and then approves and determines supportability of scheduled maintenance tasks. The output of the ERRP is translated to a work specification and then to the Air and Missile Requirements brochure, which documents requirements to the supply chain and is used to forecast the parts requirements for the following 5 years. See the entry for Brochure.

Enhanced Technical Information Management System – A USAF technical order (TO) management system that provides a near real-time, web-based, single point of access to electronic TOs, with managed configuration and controlled access to authorized users only.

Enterprise Solution-Supply (ESS) – An online tool gives logisticians the ability, with a single query, to quickly find parts stored in any of the more than 300 Air Force depot- or base-level supply accounts. It is one of three components of the Integrated Logistics System-Supply.

Equivalent Flight Hours – The flight hours determined from the actual flight hours flown multiplied by a damage index that is affected by the severity of flight conditions in which the aircraft is flown. The usage severity reflects the operational weight and maneuver loads at which the aircraft is flown and is determined from damage index data stored in the individual aircraft-tracking database, which is part of the aircraft structural integrity program. For example, for an aircraft flown for 1,000 hours strictly according to its designed maneuver and load spectrum the equivalent flight hours would equal the number of actual flight hours. If the aircraft was flown much more benignly than the designers assumed, the equivalent hours would be less than the 1,000 actual hours. Conversely, if the aircraft was flown in a much more severe manner than was assumed for the original design, 1,000 actual hours might equal 2,000 equivalent hours. Thus, the

planned structural lifetime of an aircraft can be "used up" quicker or slower than its actual in-service hours would otherwise indicate. For example, some models of the F-16 started showing signs (cracks, etc.) of reaching its service life in just 3,500 hours for some components, even though the F-16 was designed for 6-8,000 actual flight hours. This was because it was being used harder than had been assumed when it was designed, thus the equivalent flight hours were far exceeding the actual flying hours.

F-15C/D – The F-15 Eagle is an all-weather tactical fighter designed to gain and maintain air superiority in aerial combat. The F-15C Eagle is an updated version of the F-15A. The F-15D is a two-place version of the F-15C. It entered the Air Force inventory beginning in 1979 and has many improvements including additional internal fuel, provision for carrying exterior conformal fuel tanks and increased maximum takeoff weight. Additional enhancements include an upgraded central computer; ability to employ advanced versions of various air-to-air missiles; an expanded electronic warfare system, and radar improvements.

F-16C/D (Block 40, Block 50) – The F-16 Fighting Falcon is a multi-role tactical fighter aircraft flown by the USAF and numerous other Air Forces around the world. The F-16 Block 40 series is the improved all-day/all-weather strike variant equipped with LANTIRN pod and features strengthened and lengthened undercarriage, an improved radar, and a Global Position System (GPS) receiver. Block 50 F-16s have an improved GPS/Inertial Navigation System, and the ability to carry additional advanced munitions such as the AGM-88 High speed Anti-Radiation Missile, Joint Direct Attack Munition, Joint Stand Off Weapon, and Wind Corrected Munitions Dispenser.

F-22 Raptor – A USAF fighter aircraft that utilizes stealth technology. It is primarily an air superiority fighter but has multiple capabilities including ground attack. It normally carries its munitions internally to preserve its stealth characteristics but can carry additional munitions on external hard points if required.

F-35 Lightning II – A single-seat, single-engine, stealth-capable military strike fighter aircraft currently in development for the USAF and other Services as well as a number of foreign countries. It is a multi-role aircraft that can accomplish close-air support, tactical bombing, and air superiority.

Far Term – 10-15+ years from the date of the study. For this SAA Study the far-term would be defined as 2021-2026 or later.

Fiscal Year (FY) – For the United States Government, the period covering 1 October to 30 September (12 months).

Fleet Viability Board – An organization within the Headquarters, USAF, that provides the Secretary of the Air Force and the Chief of Staff with technical assessments of USAF air vehicle fleets. These assessments can lead to "continue to operate and sustain," "upgrades required to maintain mission viability," and/or fleet or partial fleet retirement decisions.

Fleet Viability Prioritization Model – A web-based application providing Air Force leadership with a prioritized list regarding which USAF aircraft types need in-depth analysis by the

USAF Fleet Viability Board. It provides rough-order-of-magnitude prioritization based on mathematical analysis of USAF fleet types. See entry for Fleet Viability Board.

Foreign Object Damage (FOD) – Any damage attributed to a foreign object that can be expressed in physical or economic terms that may or may not degrade the product's required safety and/or performance characteristics. Also, FOD is an aviation term typically used to describe debris on or around an aircraft as well as damage done to an aircraft. FOD is an abbreviation often used in aviation to describe both the damage done to aircraft by foreign objects, and the foreign objects themselves. See entry for Foreign Object Debris.

Foreign Object Debris – A substance, debris or article alien to a vehicle or system which would potentially cause damage. See entry for Foreign Object Damage.

Form 107 – The Form 107, Request for Engineering Technical Assistance is used for two types of assistance needs: for Technical Assistance (TAR) and for Maintenance Assistance (MAR). A TAR is used for engineering support/disposition and a MAR requests depot maintenance action. The Form 107 provides advice, assistance, disposition, and training pertaining to installation, operation, and maintenance of equipment using authorized procedures. It can also provide authorization for one-time repairs or time definite repair opportunities beyond what is spelled out in existing technical orders and can also provide the one-time authority to use a specific part/commodity with defects or deviations beyond technical order limits and/or provide authorization for limited use of non-listed substitutes (supplies, components, support equipment, etc.) to prevent mission impairment.

Form 202 – The AFMC Form 202, Non-Conforming Technical Assistance Request/Reply, is used by a maintenance activity to request technical assistance from the responsible engineer or equipment specialist when published technical data are not considered adequate. A maintenance activity also uses AFMC Form 202 to request technical assistance in the event of parts or material shortages.

Future Years Defense Program (FYDP) – A DoD database and internal accounting system that summarizes forces and resources associated with programs approved by the Secretary of Defense. Its three parts are the organizations affected, appropriations accounts (Research, Development, Test and Evaluation (RDT&E), Operations and Maintenance (O&M), etc.), and the 11 major programs (strategic forces, mobility forces, R&D, etc.). The FYDP allows a "crosswalk" between DoD's internal system of accounting via eleven major programs and the six major Congressional appropriations for DoD. The primary data element in the FYDP is the Program Element. The FYDP is updated annually and covers the prior year, current year, budget year, and the following four years (i.e., the "outyears").

Global Air-Traffic Management (GATM) – A concept for satellite-based communication, navigation, surveillance and air traffic management. The Federal Aviation Administration and the International Civil Aviation Organization established GATM standards to keep air travel safe and effective in increasingly crowded worldwide air space. Many older aircraft (e.g., the USAF's KC-135, C-130, and C-5) have required extensive and expensive avionics upgrades/modernization to be able to take advantage of

GATM and to avoid the operating restrictions (operating routes, altitudes, etc) to which non-GATM capable aircraft are subject.

Global Positioning System (GPS) – A satellite constellation that provides highly accurate position, velocity, and time navigation information to users. Each satellite continuously emits a pair of signals by which the system's precision and accuracy are achieved. GPS receivers employed by various users can provide positioning accuracy to within centimeters.

High Velocity Maintenance (HVM) – The HVM concept, compared to previous depot maintenance practices, involves bringing an aircraft into the depot for maintenance more frequently but for shorter durations of time. For example, a cargo aircraft would be brought to depot once every 18 months instead of once every five years. A specific example would be that of a C-130, which would remain at the depot for 12 to 15 days every 18 months, compared with up to 160 days per regular depot visit.

Home Station Check (HSC) – Consists of heavy maintenance inspections such as isochronal inspections, which are offset from HSCs by 180 days, and the more infrequent programmed depot maintenance (PDM), which usually involves major tear-down and repair actions. These inspections normally drive the planned depot actions.

Hot Corrosion – When aircraft systems (e.g., jet engines, structural components exposed to hot exhaust gases, etc.) operate at high temperatures (650-1,100 degrees Centigrade) and involve the contact of metallic or ceramic materials with combustion product gases or other oxidizing gases containing inorganic impurities a very severe corrosive environment may be created. As the gases are cooled, fused salt films can condense on the hardware to generate a highly corrosive condition analogous in some aspects to aqueous atmospheric corrosion. "Normal" expected corrosion rates may be accelerated (increased severity, reduced time) by orders of magnitude under such conditions.

Individual Aircraft Tracking (IAT) – The objective of IAT is to provide data on each aircraft that reflects differences in usage from that of the baseline design load and usage spectrum. Various required structural inspections/modifications are based on an assumed usage. The IAT effort accounts for differences in such usage among individual aircraft. Data can be gathered through aircrew reporting (after each flight) and/or automated data collection systems that can download their usage data (g-loads, maneuvers, landings, pressurization cycles, etc). IAT data is essential in the computation of equivalent flight hours for each aircraft. See entry for Equivalent Flight Hours.

Integrated Data for Maintenance (IDM) – A web-based program/platform under development to host the Technical Orders (TOs) for USAF weapons systems and also manage user accounts world-wide. It will deliver, track, and validate TO files across any network and deliver them to any viewing device. It includes a part number database for managing, updating, and viewing parts data for weapon systems. It also includes a collaboration capability to facilitate the review, verification, and validation of change data. Parts of the IDM platform are in use.

Integrated Maintenance Data System (IMDS) – The standard Air Force system for maintenance information. All maintenance information is intended to be accessible for collection, storage, and dissemination of critical data for repair and improvement of Air

Force weapon systems and equipment. IMDS functions as a single logical data base that accesses historical and legacy data stored in other data bases.

Integrated Maintenance Information System (IMIS) – The operational tool that records and networks real fleet-wide maintenance information. IMIS is intended to improve the capabilities of aircraft maintenance organizations by providing technicians with a single information system for intermediate and organizational maintenance.

Initial Operational Capability (IOC) – In general, attained when some units and/or organizations in the force structure scheduled to receive a system (1) have received it and (2) have the ability to employ and maintain it. The specifics for any particular system IOC are defined in that system's Capability Development Document and Capability Production Document.

Item Manager – An individual within the organization of an inventory control point or other such organization assigned management responsibility (e.g., ensuring the appropriate quantities of an item are procured and maintained in stock) for one or more specific items of materiel. Item managers perform materiel management functions such as worldwide item distribution and redistribution, materiel requirements determinations, budget estimates, cataloging, repair programs, and other related functions.

Joint Computer-Aided Acquisition and Logistics Support (JCALS) – A multi-Service, geographically distributed client-server system designed to process all data and information required to manage, control, and produce each Service's technical manuals at designated technical manual processing sites.

Joint Engineering Data Management Information and Control System (JEDMICS) – A DoD initiative for the management and control of engineering drawings and related text in a standard repository.

Joint Reliability Availability Management System (JRAMS) – A USAF integrated information management system developed by Southwest Research Institute that provides a suite of analysis tools to support aircraft maintenance, supply, operations, and availability management. JRAMS provides a tool to assist equipment, system, and aircraft managers effectively apply limited resources to meet mission responsibilities.

KC-135 Stratotanker – A large Boeing four-engine jet transport aircraft designed to refuel other aircraft in flight. About 732 were built (production started in 1956 and ended in 1965) and the USAF continues to operate over 400 of them. The current main version of the KC-135 is the KC-135R, which has upgraded engines, structure, and avionics compared to the original KC-135A. When operated in its transport role the KC-135 can carry up to 83,000 pounds of cargo. Several variants of the KC-135 airframe remain in service in reconnaissance, special mission, test, and other roles.

Laser Shearography – Shearography is a whole field, real-time imaging technique that reveals out-of-plane deformation derivatives in response to an applied stress. Laser shearography uses the coherent, monochromatic properties of laser light to generate speckle patterns. First, the component to be inspected is illuminated by the laser. The surface reflects the light creating a pattern at the viewing plane, which can be processed to provide information such as the presence of defects, material degradation, or residual stresses.

The system also records the pattern from an unstressed component surface. The image is recorded using a video camera, digitized and stored on a computer. The surface is then stressed and a new speckle pattern generated, recorded, and stored. The computer subtracts the speckle patterns from each other, thus forming an image made up of series of characteristic black and white fringes, representing the surface strain in the area of interest. If a defect exists, this will affect the surface strain and the defect can be revealed by the fringe pattern developed. Laser shearography is a useful tool in the detection of debonds and voids in many different materials, such as laminates, composites, honeycomb structures, and foam insulation. The first reported large scale application was to non-destructive inspection activities on the B-2 bomber.

Legacy Aircraft – An aircraft type (mission design series) that has been superseded by a newer, in-development or in-service type (even if the older type remains in production for other users). Examples for the USAF include but would not necessarily be limited to the F-15 and F-16 fighters, A-10 attack aircraft, B-52 and B-1 bombers, C-130 E/H and C-5 transports, and the KC-10 and KC-135 aerial tankers.

Life Cycle Management Plan (LCMP) – The LCMP consolidates two previous plans, the Single Acquisition Management Plan and Product Support Management Plan, into a single document that integrates both the acquisition and sustainment strategies and provides all support requirements of a system, subsystem, or major end item.

Life Cycle Sustainment Plan – Sustainment planning and execution intended to seamlessly span a system's entire life cycle, from Materiel Solution Analysis to disposal. It translates force provider capability and performance requirements into tailored product support to achieve specified and evolving life-cycle product support availability, reliability, and affordability parameters.

Line Replaceable Unit (LRU) – A modular component designed to be replaced quickly at an operating location. An LRU is usually a sealed unit such as a radio, flight control computer, power supply, or other auxiliary equipment. LRUs improve maintenance operations, because they can be stocked and replaced quickly from on-site inventory, restoring the system to service, while the failed (unserviceable) LRU is undergoing maintenance.

Logistics, Installations, and Mission Support-Enterprise View – LIMS-EV is a part of the USAF eLog 21 program and is intended to provide the Air Force logistics enterprise with near-real time data on the location, quantity, and status of Air Force resources. It also provides a suite of logistics reporting and performance analytics capabilities including weapon system availability as well as munitions, vehicle, support equipment, and supply chain management status. See entry on eLog21.

Longeron – A fore-and-aft framing member of an airplane fuselage. Longerons often carry large bending loads and also help to transfer skin loads to internal structure. Note: It was an in-flight failure of the upper right longeron, a critical support structure in the F-15C Eagle, which caused the crash of a USAF F-15C in 2007 and led to a lengthy grounding of that (aging) aircraft type.

Low Observable – Usually refers (in military aviation) to an airborne platform that is hard to detect by radar and (sometimes) infrared means. Low observable aircraft reduce their

signature via a combination of design features to reduce visibility in the visual, audio, infrared and radio frequency spectrum. Examples include the USAF's B-2 bomber and the F-22 fighter. Achieving a minimal radar cross section is normally a prerequisite to achieve low observability and normally requires there be no protruding sensors or weapons or visible airframe openings/cavities.

Maintenance, Repair, and Overhaul (MRO) – Used to describe inspection/repair of major aircraft components. MRO activities may be conducted by independent MRO companies that provide such services to all paying customers ("MRO" is often used as a synonym for any such independent entity). MROs can normally perform any level of maintenance (scheduled or unscheduled repair, overhaul, inspection, preventive, etc.) for any type of aircraft on which they have been certified as qualified. Normally MROs are considered distinct from original equipment manufacturers (OEM) although some OEMs may offer MRO services both for aircraft/components they manufacture and for others. In practical use, US Air Force depots (Air Logistics Centers) can be considered as being MRO entities although they provide many additional services.

Maintenance Steering Group 3 (MSG-3) – A structured process used to develop maintenance and inspection tasks and intervals for an airplane. It is also a decision-logic process for determining by reliability principles the initial scheduled maintenance requirements for new aircraft and/or engines. MSG-3 analysis output is used as the basis to set the principles for each MRO to develop a maintenance schedule for an aircraft type. See the entry for MRO.

Major Command, Lead Major Command (MAJCOM) – A Major Command is the highest level of command except for Headquarters Air Force (HAF). The USAF is organized on a functional basis in the United States and a geographical basis overseas. A MAJCOM represents a major Air Force subdivision having a specific portion of the Air Force operational or support mission. Each MAJCOM is directly subordinate to HAF.

A Lead MAJCOM serves as lead command for defining, advocating, and directing sustainment and modernization strategies for certain assigned mission areas and systems. A lead command develops and prioritizes science and technology mission area investment needs and manages innovation, experimentation, and technology transition efforts. It programs and budgets for AF-wide acquisition of assigned systems (e.g., Air Combat Command programs for the F-35 procurement) and engages with other Air Force major commands, joint and coalition partners, and national agencies to develop strategies and initiatives to conduct and improve the conduct of assigned mission areas. The Air Force assigns responsibility for overall management of each system to a "lead command" to ensure that all requirements associated with every system receive comprehensive and equitable consideration. The identity of the lead command is obvious when only one command has the system assigned to it. However, when Major Commands "share" a system among themselves or with units of the Air Reserve Components), the Air Force clearly designates a lead command so that all using and supporting organizations know who is the overall advocate for that system over its life cycle.

Manufacturing Readiness Level (MRL) – A measure used by the Department of Defense to assess the maturity of manufacturing readiness. It serves much the same purpose as Technology Readiness Levels (see below). MRLs are quantitative measures used to

assess the maturity of a given technology, component or system from a manufacturing perspective and are usually used to provide a common understanding of the relative maturity and attendant risks associated with manufacturing technologies, products, and processes being considered. In 2011, consideration of manufacturing readiness and related processes of potential contractors and subcontractors was made mandatory as part of the source selection process in major acquisition programs.

MRL	Description
1	Basic manufacturing implications identified. Basic research expands scientific principles that may have manufacturing implications. The focus is on a high level assessment of manufacturing opportunities. The research is unfettered.
2	Manufacturing concepts identified. Manufacturing science and/or concept described in application context. Identification of material and process approaches are limited to paper studies and analysis. Initial manufacturing feasibility and issues are emerging.
3	Manufacturing proof of concept developed. Analytical or laboratory experiments to validate paper studies are conducted. Experimental hardware or processes are created, but are not yet integrated or representative. Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required.
4	Capability to produce the technology in a laboratory environment. Required investments, such as manufacturing technology development identified. Processes to ensure manufacturability, producibility, and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks are identified for prototype build, manufacturing cost drivers are identified, and producibility assessments of design concepts have been completed. Key design performance parameters are identified and special needs identified for tooling, facilities, material handling, and skills.
5	Capability to produce prototype components in a production relevant environment. Manufacturing strategy refined and integrated with a Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling and test equipment, as well as personnel skills, have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development.
6	Capability to produce a prototype system or subsystem in a production relevant environment. Initial manufacturing approach developed. Majority of manufacturing processes have been defined and characterized, but there are still significant engineering/design changes. Preliminary design of critical components completed. Producibility assessments of key technologies complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on subsystems/ systems in a production relevant environment. Detailed cost analysis includes design trades. Cost targets have been allocated. Producibility considerations shape system development plans and long lead and key supply chain elements are identified. Industrial Capabilities Assessment for Acquisition Decision Milestone B have been completed.

7 Capability to produce systems, subsystems, or components in a production representative environment. Detailed design is underway. Material specifications are approved. Materials available to meet planned pilot line build schedule. Manufacturing processes and procedures are demonstrated in a production representative environment and detailed producibility trade studies and risk assessments underway. Cost models are updated with detailed designs, rolled up to system level, and tracked against targets. Unit cost reduction efforts are underway. Supply chain and supplier Quality Assurance are assessed and long lead procurement plans are in place. Production tooling and test equipment design and development have been initiated.

8 Pilot line capability demonstrated and ready to begin low rate production. Detailed system design essentially complete and sufficiently stable to enter low rate production. All materials are available to meet planned low rate production schedule. Manufacturing and quality processes and procedures have been proven in a pilot line environment, under control and ready for low rate production. Known producibility risks pose no significant risk for low rate production. Engineering cost models are driven by detailed design and validated. Supply chain is established and stable. Industrial Capabilities Assessment for Acquisition Decision Milestone C completed.

9 Low Rate Production demonstrated and capability in place to begin Full Rate Production. This is the highest level of production readiness. Engineering/design changes are few and generally limited to quality and cost improvements. System components or items are in rate production and meet all engineering, performance, quality, and reliability requirements. All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. Full Rate Production unit cost meets goal, and funding is sufficient for production at required rates. Lean practices are well established and continuous process improvements ongoing.

Mean Time Between Failures (MTBF) – The predicted (or experienced) elapsed time between inherent failures of a system during operation. MTBF can be calculated as the arithmetic mean (average) time between failures of a system. The definition of MTBF depends on the definition of what is considered a system failure. For complex, repairable systems, failures are considered to be those out of design conditions which place the system out of service and into a state for repair. Failures which occur that can be left or maintained in an unrepaired condition, and do not place the system out of service, are not considered failures.

Mechanical and Subsystems Integrity Program (MECSIP) – A series of disciplined time phased actions, procedures, analyses, tests, etc. intended to ensure reliable, affordable, and supportable aircraft equipment and subsystems, thus contributing to the enhancement of total systems mission effectiveness and operational suitability. MECSIP applies to subsystems and equipment whose operation is primarily electrical or mechanical (e.g., environmental control, fuel, flight controls, auxiliary power, electric power and wire, hydraulic systems, wheels, tires and brakes, auxiliary power, etc.).

MICAP – Mission Capability or Mission Impaired Capability Awaiting Parts. A term used to describe a maintenance or supply action for a system that is not mission capable due to the lack of available parts. In general a "MICAP" designation or use of the term implies

a higher priority action request within the military logistics system for obtaining, transporting, and installing the part(s). A similar term in commercial aviation is the "Aircraft on Ground" designation.

Micro-Electro-Mechanical System – The integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through micro fabrication technology. While the electronics are fabricated using integrated circuit process sequences, the micromechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form mechanical and electromechanical devices.

Mid-Term – Five to ten years from the date of the study. For this SAA Study the mid-term range would be defined as 2016-2021.

Milestone A – A DoD acquisition program milestone is a point at which a recommendation is made and approval sought regarding starting or continuing an acquisition program, i.e., proceeding to the next phase. Milestone A is that decision point that approves entry into the Technology Development phase.

Minimum Equipment List (MEL) – A categorized list of systems, instruments, and equipment on an aircraft which are not required to be operative for flight. Although an equipment item may not absolutely be required to be operative, specific restrictions, procedures, or conditions may be required for continued aircraft operation with the item inoperative. Each aircraft model generally has a distinct MEL.

Mission Capable, Mission Capable Rate – Material condition of an aircraft indicating it can perform at least one and potentially all of its designated missions. Mission capable is also defined as the sum of full mission capable and partial mission capable. The mission capable rate is also a composite metric which relates the percentage of possessed hours that an aircraft is partially or fully mission capable.

Mission Design Series (MDS) – A series of numbers and letters that describe the basic mission of the aircraft, modifications to the aircraft, manufacturer, etc. These numbers and letters represent the MDS. All US military aircraft were given a two-part MDS symbol or designation when the Department of Defense unified all military aircraft designations under a common designation system. The first part is a letter, which tells the kind of aircraft and the second part is a number which tells the model of the aircraft.

Moore's Law – The term given to a long-term trend in the history of computing hardware whereby the number of transistors that can be placed inexpensively on an integrated circuit doubles approximately every two years. The capabilities of many digital electronic devices are strongly linked to Moore's law including processing speed, memory capacity, sensors, etc.

Multi-disciplinary University Research Initiative (MURI) – A program administered through the Army Research Office, the Office of Naval Research, and the Air Force Office of Scientific Research. MURI supports university research efforts intersecting more than one traditional science and engineering discipline.

National Stock Number (NSN) – Also called "NATO Stock Number." A 13-digit numeric code, identifying all the "standardized material items of supply" as they have been

recognized by all NATO countries including United States Department of Defense. An item having an NSN is said to be "stock listed." The NSN replaced the 11-digit Federal Stock Number which was used from 1949 to 1975.

Near Term – Zero to Five years from the date of the study. For this SAA Study the near-term range would be defined as 2011-2016.

Non Destructive Inspection (NDI) – The examination of an object or material with technology that does not affect its future usefulness. NDI can be used without destroying or damaging a product or material. NDI includes many methods that can detect internal or external imperfections; determine structure, composition, or material properties; and measure geometric characteristics. Commonly used non-destructive inspection methods include liquid penetrant, magnetic particle, eddy current and radiographic (x-ray) inspection, ultrasonic inspection, tomography, and real-time radiography.

Not Mission Capable Both (NMCB) – Material condition indicating that systems and equipment are not capable of performing any of their assigned missions because of maintenance requirements as well as work stoppage due to a supply shortage. See Not Mission Capable Maintenance and Not Mission Capable Supply below.

Not Mission Capable Maintenance (NMCM) – Material condition indicating that systems and equipment are not capable of performing any of their assigned missions because of maintenance requirements. See also not mission capable supply (below).

Not Mission Capable Supply (NMCS) – Material condition indicating that systems and equipment are not capable of performing any of their assigned missions because of maintenance work stoppage due to a supply shortage. See also not mission capable maintenance (above).

Operational Flight Program (OFP) – The embedded software that performs the functions and sub-functions necessary for aircraft (or aircraft systems) to operate in flight. Most changes to munitions or additions of munitions systems to aircraft require extensive testing to certify the changes to the aircraft's OFP (or to ensure no OFP changes are needed).

Operations and Maintenance (O&M) – O&M appropriations traditionally finance those things whose benefits are derived for a limited period of time, i.e., expenses, rather than investments. Examples of costs financed by O&M funds are headquarters operations, civilian salaries and awards, travel, fuel, minor construction projects of $750K or less, expenses of operational military forces, training and education, recruiting, depot maintenance, purchases from Defense Working Capital Funds (e.g., spare parts), base operations support, and assets with a system unit cost less than the current procurement threshold ($250K). O&M appropriations are normally available for obligation for only one fiscal year.

Operations and Support – All direct and indirect costs incurred in using the system, e.g., personnel, maintenance (unit and depot), and sustaining investment (replenishment spares). The bulk of any system's total life cycle costs are in this category, which is normally composed of funds from the O&M (see above) and Military Personnel appropriation accounts.

Original Equipment Manufacturer (OEM) – The entity that manufactures and sells products under its own name. Or, components that are purchased by an OEM and retailed under that purchasing entity's brand name. In general, when referring to aging aircraft, OEM refers to the original aircraft manufacturer (or its business successor) that sold the aircraft to the USAF.

Pacer Compass, Radar, and GPS (Pacer CRAG) – A USAF KC-135 modernization program that ran from 1995 through 2002. It involved a major overhaul of the cockpit to improve the reliability and maintainability of the aircraft's systems and install GPS. Upgrades included color weather radar, improved compass and radar systems, and an on-board GPS. Also, a traffic collision avoidance system and new central air data computer were added. The later GATM upgrades were then added on top of and integrated with the Pacer CRAG modifications and the combined Pacer CRAG/GATM program was completed in 2010. See GATM entry.

Pareto Analysis – A statistical technique in decision making that is used for selection of a limited number of tasks that produce significant overall effect. It uses the principle that a large majority of effects (80%) are produced by a few key causes (20%).

Part 121 Aviation – A shorthand term used to refer to scheduled air carrier operations. It derives from the relevant portion of the Federal Aviation Regulations (Part 121: "Operating Requirements: Domestic, Flag, and Supplemental Operations") that prescribes in detail the exacting requirements to operate such an air carrier.

PBD-720 – Each budget year, many Program Budget Decisions (PBDs) are issued by the Office of the Secretary of Defense. These PBDs modify the Military Services' suggested budgets. Once all of the PBDs are issued and resolved with the Services, the DoD budget is submitted to the Congress as a part of the President's Budget. In recent common use within the USAF, the term "PBD-720" refers to a specific PBD issued in late 2005 that affected the Fiscal Year 2007 and later years' budget baselines. Among other effects, it made substantial reductions in USAF military, civilian, and contract personnel accounts (over 40,000 positions) to fund force modernization and help reach various budget reduction goals. Many of these reductions affected manpower positions (military and civilian) that provided aircraft sustainment activities at both the field and depot levels.

Performance Based Outcome (PBO) – A type of contracting (often associated with Performance Based Logistics concepts) that allows payment for a level of performance or a certain outcome defined by a performance level rather than the more traditional delivery of transactional goods and/or services. PBO contracting is perceived by Aerospace and Defense Industry, the Department of Defense, and commercial airline industry as being able to decrease lifecycle costs while improving end-customer satisfaction. "Power by the Hour" would be one example of a performance based outcome approach. See Glossary entry for "Power by the Hour."

Point of Maintenance (POMX) – A part of the eLog21 initiative, POMX consists of a wireless local area network, ruggedized handheld terminals for use by maintenance technicians, and a dedicated server for receiving and synchronizing data, and laptop and desktop computers for interfacing and analysis. It improves information flow to and from the maintainer while reducing data input requirements (e.g., through barcode readers) and

also provides an error-checking function through an intelligent interface. See entry for eLog21.

Portable Maintenance Aid – An interactive maintenance tool that allows mechanics and engineers to analyze and solve aircraft problems at the work site (hanger, shop floor, flight line, etc.). Such a tool will normally have all relevant maintenance documentation (operating and maintenance procedures, technical drawings, etc.) available for display to the user.

Power by the Hour – A term used to describe a support service whereby for a fixed sum per flying hour, a complete engine and accessory replacement service is provided, thus allowing the operator to accurately forecast costs, relieving the operator of the requirement to purchase stocks of engines and accessories. The key feature of the program is that it undertakes to provide the operator with a fixed engine maintenance cost over an extended period of time.

Primary Aircraft Inventory (PAI) – The total number of aircraft assigned to a given unit to meet the primary aircraft authorization.

Principal Component Analysis – A mathematical procedure that transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible. It is mostly used as a tool in exploratory data analysis and for making predictive models.

Product Support Integrator (PSI) – The PSI nomenclature replaces System Support Manager or System Sustainment Manager (SSM). The PSI is an entity within the Federal Government or outside the Federal Government charged with integrating all sources of product support, both private and public, defined within the scope of a product support arrangement. The PSI provides functional support to the Product Support Manager (PSM). See entry for PSM.

Product Support Manager – The individual with responsibility to lead the development, implementation, and top-level integration and management of all sources of support to meet Warfighter sustainment and readiness requirements. The PSM develops and implements a comprehensive product support strategy for each applicable program. The PSM reports directly to, and is accountable to, the program manager (PM) for the execution of all product support requirements within the PM's scope of responsibilities. The PSM has the responsibility to interface directly with lead and supporting commands' logistics, installation, and mission support functional authorities to ensure execution of readiness requirements.

Product Support Provider (PSP) – The PSP is an entity that provides product support functions. The term includes an entity within the Department of Defense, an entity within the private sector, or a partnership between such entities.

Program of Record – A program which has survived the POM/Budget formulation process and is listed (and thereby appropriately funded) in the Future Years Defense Program (FYDP). The two primary elements of a FYDP are Program Element (PE) and Resource

Identification Code (RIC) and a program of record will be listed as a PE or within a PE. See entry for FYDP.

Programmed Depot Maintenance – The (normally) periodic inspection and correction of defects that require skills, equipment, or facilities not normally possessed by operating locations. It is complex, usually lengthy (2-6 months) and expensive ($1M+), and is governed by numerous technical orders and policy directives.

Program Objective Memorandum (POM) – The final product of the DoD Components' internal programming processes, the POM is submitted to the Secretary of Defense (SecDef) by the DoD Component heads (including the Secretary of the Air Force). The USAF POM recommends the USAF's total resource requirements and programs within the parameters of SecDef's fiscal guidance and shows programmed needs for the six years of the Future Years Defense Program (FYDP) (i.e., in FY 2010, POM 2012-2017 was submitted). The SecDef responds to the Component POMs by approving those subject to (many) modifications. After an iterative process between the Components and the Office of the Secretary of Defense regarding those modifications, the POM, as modified, becomes the Components' budgets that are submitted to SecDef and then to the Congress by the President.

Propulsion Systems Integrity Program (PSIP) – An organized and disciplined engineering and management process to assure that the integrity of the engine is achieved in the development program and maintained throughout operational service. The PSIP process consists of phased tasks that increase knowledge of the true characteristics of the propulsion system being developed. The goal of PSIP is to use the knowledge gained from these tasks to balance cost and risk and maximize product maturity and effectiveness. PSIP applies to USAF air vehicles which have a propulsion system based on or powered by a gas turbine engine.

Quadrennial Defense Review (QDR) – A legislatively-mandated review of the US Department of Defense strategies and priorities that is conducted every four years by the DoD. The QDR sets a long-term course for the DoD as it assesses priorities and challenges that the United States faces. It rebalances the DoD's strategies, capabilities, and forces to address current conflicts and future threats. The Quadrennial Defense Review Report is the main public document describing the military doctrine of the United States.

Radiometrix Ultra High Frequency (UHF) Frequency Modulated (FM) Data Transmitter and Receive Modules – A printed circuit board mounted UHF FM radio transmitter and receiver pair which enables implementation of a short range data link. It may be used for one-to-one and multi-node wireless links in applications including electronic point of sale and inventory tracking, remote industrial process monitoring, and computer networking. Because of their small size and low power requirements, these type modules are well-suited for use in portable, battery-powered applications such as hand-held terminals.

Readiness – The ability of US military forces to fight and meet the demands of the national military strategy. Readiness is the synthesis of two distinct but interrelated levels:
(1) Unit readiness: The ability to provide capabilities required by the combatant commanders to execute their assigned missions. This is derived from the ability of each unit to deliver the outputs for which it was designed.

(2) Joint readiness: The combatant commander's ability to integrate and synchronize ready combat and support forces to execute his or her assigned missions.

Reliability and Maintainability Information System (REMIS) – The Air Force's central database for equipment that provides near-real time on-line data for tracked aircraft and equipment to DoD, Air Force, and MAJCOM staffs. The system interfaces with a multitude of other DoD and contractor systems; however, the majority of Air Force aircraft and engine data are transferred into REMIS from the Core Automated Maintenance System or the Comprehensive Engine Management System.

Reliability Based Maintenance (RBM) – A process that describes maintenance as a reliability function as opposed to a repair function. Traditional maintenance definitions refer to repairing equipment when it malfunctions or breaks. RBM considers maintenance to consist of four types:

(1) Reactive Maintenance: Breakdown-based, where mechanics respond to equipment problems.

(2) Preventive Maintenance: Time-based, where mechanics perform basic inspections and replenish consumables (e.g., lubricating oil, air, hydraulic fluids, etc.), repair and replace parts on a pre-planned interval, and manage spare parts inventories.

(3) Predictive Maintenance: Condition-based, where mechanics use condition monitoring instruments (infrared, ultrasound, motor current analysis, oil analysis, etc.) to track equipment conditions and make adjustments before equipment breaks down.

(4) Proactive Maintenance – Design-based, where mechanics and engineers design equipment for longer service life, ease of maintainability, reliability, and serviceability.

Reliability Centered Maintenance (RCM) – A process to establish the safe minimum levels of maintenance and is generally used to achieve improvements in fields such as the establishment of safe minimum levels of maintenance, changes to operating procedures and strategies, and the establishment of capital maintenance regimes and plans. With respect to aviation, RCM is used to create a maintenance strategy to address dominant causes of equipment failure and provides a systematic approach to defining a routine maintenance program composed of cost-effective tasks that preserve important functions. RCM can lead to increases in cost effectiveness, system/component uptime, and a greater understanding of the level of risk that an organization is currently managing.

Remotely Piloted Aircraft (RPA) – A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Note: Also referred to as Unmanned Aerial Vehicle (UAV).

Resonant Tunneling Diode – A type of electronic component with nonlinear resistance and conductance employing a resonant-tunneling structure in which electrons can tunnel through some resonant states at certain energy levels. These diodes make use of quantum mechanical tunneling. Tunneling diodes can be very compact and are also capable of ultra-high-speed operation.

Return on Investment (ROI) – A performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments. To

calculate ROI, the benefit (return) of an investment is divided by the cost of the investment; the result is expressed as a percentage or a ratio.

Rivet Joint – The RC-135V/W Rivet Joint reconnaissance aircraft supports theater and National level consumers with near real time on-scene intelligence collection, analysis, and dissemination capabilities. The aircraft is an extensively modified KC/C-135. The Rivet Joint's modifications are primarily related to its on-board sensor suite, which allows the mission crew to detect, identify and geolocate signals throughout the electromagnetic spectrum. The mission crew can then forward gathered information in a variety of formats to a wide range of consumers via an extensive communications suite.

Service Acquisition Executive (SAE) – The Secretaries of the Military Departments serve as the SAE (sometime "component acquisition executive") and are delegated this power/status by the Defense Acquisition Executive. The Service Secretary has the power of redelegation. In the Air Force the Assistant Secretary for Acquisition normally serves as the SAE. The SAEs are responsible for all acquisition functions within their components. This includes life cycle acquisition of systems and services processes from pre-Milestone A to weapon system retirement (e.g., research, development, test, evaluation, production, and delivery of new systems, or modifications to existing systems).

Service Life Extension – The continued use of a product and/or service beyond its original design life. It emphasizes reliability upgrades and component replacement or rebuilding of the system to delay the system's entry into wear-out status due to prohibitively expensive sustainment, reliability, safety, and/or performance requirements that can no longer be met. The goal is typically to return the system to as close to "as new" condition as possible while remaining consistent with the economic constraints of the program.

Software, Computer Software – An aggregation of computer applications and related data that provide the instructions for telling a computer what to do and how to do it. Software is often divided into application software (programs that do work users are directly interested in) and system software (which includes operating systems and any program that supports application software). Software can refer to computer programs, procedures, and associated documentation and data, pertaining to the operation of a computer system.

Software Integration Laboratory (SIL) – When a new or modified element of software is to be used on an aircraft it must be integrated into the aircraft's current software/hardware and tested to ensure that it both properly performs its design functions and does not interfere with any other software/hardware element of the aircraft's systems. A software integration laboratory is used to do verification and validation of the new software for proper functioning and to check out the integration of the new/modified software with the existing system using flight-representative hardware and software in a controlled (usually) ground-based environment where proper functioning of the new/modified system can be monitored and documented under realistic conditions. SILs are often used to support integration of aircraft subsystems, to conduct laboratory development testing that leads to aircraft ground testing, and to aid accident investigations.

Software Maintenance – The modification of a software product after delivery to correct faults, to improve performance, or modify other attributes. It consists of considerably more than fixing "bugs" as up to 80% of the maintenance effort is used for non-corrective actions. Note: Many user problem reports that are resolved via software "maintenance" actions were actually requests for functionality enhancements to the system.

Software Requirements Application (SRA) – The Air Force Materiel Command Software Requirements Review process requires the creation of various required documents including the Software Support Requirements Documentation and the Software Task Detail Description. The SRA is a database that maintains all of the information that is used to generate the forms.

Software Sustainment – the processes, procedures, people, and information required to support, maintain, and operate the software aspects of a system. Note: This is not synonymous with "software maintenance." When hardware fails, the repair person replaces the failed part with an identical but functioning part. When software fails, the software engineer does not replace the offending code with an identical piece of code; rather, the code must be modified to function correctly and then tested.

Software Verification and Validation (V&V) – Verification and validation is the process of checking that a software system meets specifications and that it fulfills its intended purpose. Verification is the part of the process that evaluates software to determine whether the products of a given development phase satisfy the conditions imposed at the start of that phase (i.e., was the software built in compliance with the requirements and specifications). Validation is the part of the process that evaluates the software during or at the end of the development process to determine whether it satisfies specified requirements (i.e., does it or does it not meet user needs even if it is in fact "built to spec").

Stress Corrosion Cracking (SCC) – The growth of cracks under sustained stress in a corrosive environment which can lead to unexpected sudden failure of normally ductile metals subjected to a tensile stress, especially at elevated temperature in the case of metals. The chemical environment that causes SCC for a given alloy is often one which is only mildly corrosive to the metal otherwise. Parts with severe stress corrosion can appear "new" while being filled with microscopic cracks. Stress corrosion cracking is often driven by residual stresses which are difficult to detect. This makes it common for stress corrosion to go undetected prior to failure. It often progresses rapidly, and is more common among alloys than pure metals.

Supply Chain Forecasting – A business-planning discipline that uses both statistical forecasting and a domain-specific expert consensus process. It is centered on (customer) demand planning, to develop demand forecasts as an input to service-planning processes, production, inventory planning, revenue, and cash-flow planning. It is generally possible to create good demand forecasts through a combination of judgmental and statistical methodologies. Statistical models based on solid historical data usually provide a good baseline which when "tweaked" by domain expert(s), can provide reliable results on a continuous basis.

Sustainment – The purpose of the sustainment effort is to execute the support program to meet operational performance requirements and sustain the system in the most cost-effective manner over its life cycle. Sustainment includes supply, maintenance, transportation, sustaining engineering, data management, configuration management, manpower, personnel, training, habitability, survivability, environment, safety (including explosives safety), occupational health, protection of critical program information, anti-tamper provisions, information technology, supportability, and interoperability functions. It also includes the provision of personnel, training, logistics, and other support required to maintain and prolong operations or combat until successful accomplishment or revision of the mission or of the national objective.

Sustainment Engineering – The technical effort required to support an in-service system in its operational environment to ensure continued operation and maintenance of the system with managed risk, including: (1) collection and evaluation of service use and maintenance data and root cause analysis of in-service problems such as operational hazards, deficiency reports, parts obsolescence, corrosion effects, reliability and maintainability trends, safety hazards, failure causes and effects, and operational usage profiles changes; (2) development of required design changes to resolve operational issues, introduction of new materials, and revising product, process, and test specifications; (3) oversight of the design configuration baselines to ensure continued certification compliance, and technical surveillance of critical safety items and approved sources for those items; and (4) periodic review of system performance against baseline requirements, analysis of trends, and development of management options and resource requirements for resolution.

Sustainment Phase – Also "operations and support" phase. That period starting when production of a system is substantially complete and stretching through the end of the system's service life. In general, 65-70% percent of the life-cycle cost of a military system is incurred during the sustainment phase.

System Program Manager (SPM) – Designated individual with responsibility for and authority to accomplish program objectives for development, production, and/or sustainment to meet the user's operational needs. The SPM is accountable for cost, schedule, and performance.

System Program Office (SPO) – A Department of Defense system program office normally is responsible for the development, acquisition, and support of a weapon system. It provides program direction and logistics support as the single face to the customer. Among other tasks, a SPO is responsible for acquisition, systems engineering and depot repair support; manages equipment spares; provides storage and transportation; and accomplishes modifications and equipment replacement to maintain the weapons system throughout its life. The SPO is headed by the System Program Manager and is the single Point of Contact with industry, government agencies, and other activities participating in the system acquisition and sustainment processes.

System Sustainment Manager (SSM) – The individual with functional responsibility for the sustainment portion of a system's life cycle in support of a SPM. According to Air Force Instruction 63-101, August 2011, the Product Support Integrator (PSI) nomenclature replaces the function of the System Support Manager or System Sustainment Manager.

The PSI is an entity within the Federal Government or outside the Federal Government charged with integrating all sources of product support, both private and public, defined within the scope of a product support arrangement. The PSI provides functional support to the PSM.

Systems Engineering – An interdisciplinary field of engineering that focuses on how complex engineering projects should be designed and managed over the life cycle of the system. Issues such as logistics, the coordination of different teams, and automatic control of machinery become more difficult when dealing with large, complex projects. "Systems engineering," in this sense of the term, refers to the distinctive set of concepts, methodologies, organizational structures, etc. that have been developed to meet the challenges of engineering very complex functional physical systems.

T-38 Talon – A twin-engine, high-altitude, supersonic jet trainer used by the USAF to prepare pilots to pilot front-line fighter and bomber aircraft. The T-38 first flew in 1959 and more than 1,100 were built through 1972. Several hundred remain in service with the USAF and it is also flown by the National Aeronautics and Space Administration, the US Navy, and the armed forces of a number of other countries. As the T-38 fleet has aged, many of its airframe, engine, avionics, and other mechanical, hydraulic, and electrical subsystem components have been modified or replaced.

Team Software Process – An approach to building and maintaining software developed by the Software Engineering Institute. This approach guides engineering teams developing software-intensive products and provides a process framework designed to help teams of managers and engineers organize projects and produce software products that range from several thousand lines of code to larger than a half a million lines of code. It is reported to have resulted in: (1) productivity enhancements of more than 25 percent, (2) reduced cost/schedule variance to less than +/- 10 percent, and (3) reductions in testing costs/schedule up to 80 percent.

Technical Order (TO) – A document that provides clear and concise instructions for the safe and effective operation and maintenance of centrally-acquired and managed Air Force military systems and end items. TOs for individual systems and end items are managed by TO Managers assigned by the responsible Program Manager or Supply Chain Manager.

Technology Readiness Level (TRL) – A measure used by many Department of Defense organizations to assess the maturity of evolving technologies (materials, components, devices, etc.) prior to incorporating that technology into a system or subsystem. Generally speaking, when a new technology is first invented or conceptualized, it is not suitable for immediate application. Instead, new technologies are usually subjected to experimentation, refinement, and increasingly realistic testing. Once the technology is sufficiently proven, it can be incorporated into a system/subsystem.

TRL	Description
1	Lowest level of technology readiness. Basic principles observed and reported. Scientific research begins to be translated into applied research and development. Example might include paper studies of a technology's basic properties.

2 Technology concept and/or application formulated. Invention begins. Once basic principles are observed, practical applications can be invented. The application is speculative and there is no proof or detailed analysis to support the assumption. Examples are still limited to paper studies.

3 Analytical and experimental critical function and/or characteristic proof of concept. Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.

4 Component and/or breadboard validation in laboratory environment. Basic technological components are integrated to establish that the pieces will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in a laboratory.

5 Component and/or breadboard validation in a relevant environment. Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so that the technology can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.

6 System/subsystem model or prototype demonstration in a relevant environment. Representative model or prototype system, which is well beyond the breadboard tested for TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high fidelity laboratory environment or in simulated operational environment.

7 System prototype demonstration in an operational environment. Prototype near or at planned operational system. Represents a major step up from TRL 6, requiring the demonstration of an actual system prototype in an operational environment, such as in an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.

8 Actual system completed and "flight qualified" through test and demonstration. Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.

9 Actual system "flight proven" through successful mission operations. Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. In almost all cases, this is the end of the last "bug fixing" aspects of true system development. Examples include using the system under operational mission conditions.

Terms of Reference – A statement of the background, objectives, and purpose of a program, project, or proposal which shows how the scope will be defined, developed, and verified.

Time and Materials (T&M) Contract – A hybrid of fixed-price and cost-reimbursement contracts which is normally used only when it is not possible to accurately estimate the extent or duration of the work or to anticipate costs with any reasonable degree of confidence. T&M contracts provide for acquiring supplies or services on the basis of

direct labor hours at specified fixed hourly rates that include wages, overhead, general and administrative expenses, and profit and the actual cost for materials. This type of contract presents the highest risk to the government and lowest risk to the contractor.

Time Limited Dispatch (TLD) – A method of allowing dispatch of an aircraft into operational service for limited time periods with a redundant system that has one or more failed elements that individually or in combination do not prohibit function within the system. The redundancy has to have been demonstrated to assure average system performance reliability as good as or better than a specified level. TLD reduces mission delays/cancellations, allows for aircraft to be dispatched into service with degraded (but still acceptable) redundancy, and takes advantage of redundancy to permit required maintenance to be scheduled at more optimum intervals/locations.

Total Aircraft Inventory (TAI) – Number of aircraft assigned to operating forces (or to a given unit) for mission, training, test, or maintenance functions.

Total System Performance Responsibility (TSPR) – A contracting and acquisition management approach in favor during the 1990s whereby many "normal" government program management tasks are transferred to the contractor in order to gain efficiencies by taking advantage of a contractor's overall management approach and commercial practices with reduced government oversight. "Gaining efficiencies" included identifying redundant and/or unnecessary practices; eliminating those practices; and in their place, using commercial practices to improve the acquisition process. TSPR can be a very complex relationship to put on a contract and normally begins by requiring a contractor to propose, within existing constraints, a solution to fill a government requirement. The government then allows the contractor, with minimal oversight and adequate funding to cover proposed costs, to implement the proposed solution. The contractor is held responsible for program success. In general the overarching motivation/goal to employ a TSPR approach has been to reduce costs while maintaining or improving the quality or service levels.

Unit Possessed Not Reported (UPNR) – The percentage of a fleet's Total Active Inventory that are unit possessed, but not reported. When an aircraft suffers major damage or is in need of major maintenance, the owning unit may be required to wait for higher headquarters to make a decision regarding how to proceed. During this time, the aircraft would be UPNR because the unit is waiting to be told what to do next. See Total Active Inventory.

Unmanned Aerial Vehicle (UAV) – Also known as an unmanned aircraft system or remotely piloted aircraft or unmanned aircraft. It is powered aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Currently, military UAVs perform reconnaissance and attack missions. Examples include the USAF MQ-1 Predator and the MQ-9 Reaper.

Weapon System Review – Regular examinations conducted by the USAF Chief of Staff (CSAF) for each weapon system (MDS) to look at their operational and sustainment "health" (which includes reliability, maintenance, and depot activities and timelines—both current and trend data are presented). Reported metrics include aircraft availability (primary metric), various mission capable rates, deport possessed time, etc.). Plans to

improve various metrics are also presented. In addition to the less-frequent CSAF reviews, weapons system reviews are conducted quarterly at Air Force Materiel Command. See entries for Mission Design Series and Aircraft Availability.

Weapons System Sustainment (WSS) – The sustainment requirements development process first starts with the Lead Commands identifying their capability requirements in terms of Performance Based Outcomes (PBOs). These capabilities are provided to the System Program Manager who then works with the Lead Command and engineering community to document all needed tasks to deliver these capabilities. This process takes place in a fiscally unconstrained environment and forms the WSS requirement. This unconstrained WSS requirement is used by the SPMs to recommend funds spread within their programs to maximize capabilities to be delivered. The Lead MAJCOMs are provided the projected capabilities for all their PBOs as well as the buy-backs for all their weapon systems. They prioritize the buy-backs and provide those to the Centralized Asset Management office to submit to the Air Force Corporate Structure. This is transmitted as a Program Objective Memorandum submission to the AF Logistics Panel within Headquarters USAF. The Logistics Panel takes the WSS submissions and advocates for them through the Air Force Board and Air Force Council where the request is prioritized against other USAF requirements and the results are included in the AF POM and (later) Budget submission to the Office of the Secretary of Defense.

Work Unit Code – An Air Force weapons system is defined in hierarchal breakdown structure used to identify the system, specific sub system, set, major component, repairable subassembly, or individual part. The basic Work Unit Code is constructed of a series (one, three, five, or seven) alphanumeric characters that a define system, subsystem, or component part.

X-Ray Backscatter – Backscatter X-ray is an advanced X-ray imaging technology based on the Compton scattering effect of X-rays, a form of ionizing radiation. Unlike a traditional X-ray machine which relies on the sensing the transmission of X-rays through the object, backscatter X-ray detects the radiation that reflects from the object and forms an image. It has potential applications to non destructive inspection (where less-destructive examination is required) and can be used if only one side of the target is available for examination.

Appendix F: Acronyms and Abbreviations

%	Percent
$	Dollars
3D	Three Dimensional
A8, AF/A8	Deputy Chief of Staff for Strategic Plans and Programs
AA	Aircraft Availability
ABIDES	Automated Budget Interactive Data Environment System
A/C	Aircraft
ACC	Air Combat Command
AESA	Active Electrically Scanned Array
AETC	Air Education and Training Command
AF	Air Force
AFB	Air Force Base
AFCS	Air Force Corporate Structure
AFGLSC	Air Force Global Logistics Support Center
AFI	Air Force Instruction
AFMC	Air Force Materiel Command
AFOSR	Air Force Office of Scientific Research
AFPD	Air Force Policy Document
AFRL	Air Force Research Laboratory
AFSAS	Air Force Safety Automated System
AFSOC	Air Force Special Operations Command
AFTOC	Air Force Total Operational Cost
ALC	Air Logistics Center
AMARG	Aerospace Maintenance and Regeneration Center
AMC	Air Mobility Command
AMP	Avionic Modernization Program
AMR	Aircraft and Missile Requirements
AMXG	Aircraft Maintenance Group
AOR	Area of Responsibility

APPG	Annual Planning and Programming Guidance
ASC	Aeronautical Systems Center
ASIC	Application Specific Integrated Circuit
ASIMIS	Aircraft Structural Integrity Management Information System
ASIP	Aircraft Structural Integrity Program
ATA	Air Transport Association
AVCOM	Advanced Component Obsolescence Management
Avg	Average
AVIP	Avionics System Integrity Program
AWACS	Airborne Warning and Control System
BAI	Backup Aircraft Inventory
BCA	Business Case Analysis
Blk	Block
BoW	Bill of Work
C	Centigrade
CAD	Computer Aided Design
CAFDEX	Centralized Access for Data Exchange
CAM	Centralized Asset Management
CAMS	Core Automated Maintenance System
CAPS	Component Analysis and Prioritization System
Capt	Captain
CBM	Condition Based Maintenance
CBM+	Condition Based Maintenance + Prognostics
CEMS	Comprehensive Engine Management System
CIRE	Common Inspection Reporting Engine
CITE	Centers of Industrial and Technical Excellence
CLS	Contractor Logistics Support
cm	Centimeters
CNT	Carbon Nano Tube
CO	Contracting Officer
COTS	Commercial Off the Shelf

CPFH	Cost Per Flight Hour, Cost Per Flying Hour
CRAG	Compass, Radar, and Global Positioning System
CSAF	Chief of Staff of the Air Force
CSI	Critical Safety Item
CSL	Complete Service Life
CSSIP	Computer Systems and Software Integrity Program
CTO	Chief Technical Officer
CTOL	Conventional Take Off and Landing
D200 RMS	D200 Requirements Management System
DDT&E	Design, Development, Test, and Evaluation
deg	Degree, Degrees
DESTRAP	Damage Evaluation System Technical/Repair Assistance Page
DFA	Demand Forecast Accuracy
DLA	Defense Logistics Agency
DLR	Depot Level Repairable
DMAWG	Depot Maintenance Action Working Group
DMS	Diminishing Manufacturing Sources
DMSMS	Diminishing Manufacturing Sources and Materials Shortages
DoD	Department of Defense
DPEM	Depot Purchased Equipment Maintenance
Dr.	Doctor
DRIS	Diagnosis and Recommendation Integrated System (?)
DSL	Design Service Life
DSM	Development System Manager
DSOR	Depot Source of Repair
ECSS	Expeditionary Combat Support System
EFH	Equivalent Flight Hours
e.g.	For Example
eLog21	Expeditionary Logistics for the 21st Century
EN	Directorate of Engineering
Eng	Engineering

Env	Environmental
ERRP	Engineering Requirements Review Process
ESL	Economic Service Life
ESS	Enterprise Solution-Supply
ETIMS	Enhanced Technical Information Management System
EW	Electronic Warfare
FAA	Federal Aviation Administration
FFRDC	Federally Funded Research and Development Center
FH	Flight Hours, Flight Hour, Flying Hours, Flying Hour
FMEA	Failure Mode and Effects Analysis
FIN	Field Information Network
F/O	Follow On
FOD	Foreign Object Damage
FSID	Functional Systems Integrated Database
FVB	Fleet Viability Board
FW	Fighter Wing
FY	Fiscal Year
FYDP	Future Years Defense Program
G004L	Job Order Production Master System
GATM	Global Air Traffic Management
GCU	Generator Control Unit
GLSC	Global Logistics Support Center
GO81	CAMS for Tanker/Cargo Aircraft
GPS	Global Positioning System
GS	General Schedule
HAF	Headquarters Air Force
HSC	Home Station Check
HVM	High Velocity Maintenance
IAT	Individual Aircraft Tracking
ICBM	Intercontinental Ballistic Missile
ICS	Interim Contractor Support
IDM	Integrated Data for Maintenance

i.e.	That Is
IMDS	Integrated Maintenance Data System
IMIS	Integrated Maintenance Information System
Incl	Included
Insp	Inspection
IOC	Initial Operational Capability
IT	Information Technology
JCALS	Joint Computer-Aided Acquisition and Logistics Support
JDRS	Joint Deficiency Reporting System
JEDMICS	Joint Engineering Data Management Information and Control System
JRAMS	Joint Readiness Automated Management System
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Target Attack Radar System
K, k	Thousand, Thousands
KeV	Kilo Electron Volts
Labs	Laboratories
LaRC	Langley Research Center
LCMP	Life Cycle Management Plan
LCSP	Life Cycle Sustainment Plan
LIMS-EV	Logistics, Installations, and Mission Support-Enterprise View
LO	Low Observable
Log	Logistics
LRDP	Long Range Development Plan
LRPS	Long Range Persistent Strike
LRS-B	Long Range Strike-Bomber
Lt Col	Lieutenant Colonel
Lt Gen	Lieutenant General
M	Million, Millions
Maint	Maintenance
Maj	Major
MAJCOM	Major Command

Maj Gen	Major General
Max	Maximum
MCR	Mission Capable Rate
MDS	Mission Design Series
MEC	Mission Essential Capability
MECSIP	Mechanical Equipment and Subsystem Integrity Program
MEL	Minimum Equipment List
Mgmt	Management
MICAP	Mission Capability, Mission Impaired Capability Awaiting Parts
Mil, MIL	Military
MILSTD, Mil-Std	Military Standard
MILCON	Military Construction
MILPERS	Military Personnel
mm	Millimeter, Millimeters
MMIII	Minuteman 3
MMH	Maintenance Man Hours
MNCL	Master Nuclear Certification List
Mr.	Mister
MRB	Manufacturing Review Board
MRL	Manufacturing Readiness Level
MRO	Maintenance, Repair, and Overhaul
MS	Milestone
MSG	Maintenance Steering Group
MTBF	Mean Time Between Failures
MURI	Multi-disciplinary University Research Initiative
MX	Maintenance
NASA	National Aeronautics and Space Administration
NAVAIR	Naval Air Systems Command
NDI	Non-Destructive Inspection
NMCB	Non-Mission Capable Due to Both
NMCM	Non-Mission Capable Due to Maintenance

NMCS	Non-Mission Capable Due to Supply
NRC	National Research Council
NSN	National Stock Number
NTSB	National Transportation and Safety Board
OC-ALC, OCALC	Oklahoma City – Air Logistics Center
OEM	Original Equipment Manufacturer
OFP	Operational Flight Program
O&M	Operations and Maintenance
OMEI	Other Major End Items
OOALC	Ogden Air Logistics Center
OPR	Office of Primary Responsibility
Ops	Operations
Opt	Option
O&S	Operations and Support, Operations and Sustainment
OSD	Office of the Secretary of Defense
PAI	Primary Aircraft Inventory
PB	President's Budget
PBD	Program Budget Decision
PBL	Performance Based Logistics
PBO	Performance Based Outcome, Performance Based Outcomes
PCA	Principle Component Analysis
PCS	Permanent Change of Station
PDM	Programmed Depot Maintenance
PDMSS	Programmed Depot Maintenance Schedule System
PEO	Program Executive Officer
PMO	Program Management Office
POL	Petroleum, Oil, and Lubricants
POM	Program Objective Memorandum
POMX	Point of Maintenance
PoR	Program of Record
PPBE	Planning, Programming, Budgeting and Execution

Prep	Preparation
Prof	Professor
PSIP	Propulsion System Integrity Program
PV/W	Pressure times Volume divided by Weight
R	Red
R&D	Research and Development
R2, R^2	Coefficient of Determination
RB	AFRL Air Vehicles Directorate
RCM	Reliability Centered Maintenance
RDT&E	Research, Development, Test, and Evaluation
REMIS	Reliability and Maintainability Information System
Req'd	Required
RERP	Reliability Enhancement and Re-Engining Program
Ret	Retired
RF	Radio Frequency
ROI	Return on Investment
RPA	Remotely Piloted Aircraft
RSL	Remaining Service Life
RX	AFRL Materials and Manufacturing Directorate
RZ	AFRL Propulsion Directorate
SAA	Sustaining Aging Aircraft
SAB	Scientific Advisory Board
SAF	USAF Headquarters Secretariat
SAS	Stability Augmentation System
SCC	Stress Corrosion Cracking
SCMW	Supply Chain Management Wing
SE	Sustaining Engineering
sec	Second
SecAF	Secretary of the Air Force
SIL	Software Integration Lab
SL	Senior Leader
SLEP	Service Life Extension Program

SLOC	Source Lines of Code, Software Lines of Code
SME	Subject Matter Expert
SORAP	Source of Repair Assignment Process
Spec	Specification
SPM	System Program Manager
SPO	System Program Office
SRA	Software Requirements Application
SSI	Safety Significant Item
SSM	System Sustainment Manager
S&T	Science and Technology
Std, STD	Standard
Sust	Sustainment
SW, S/W	Software
TAI	Total Aircraft Inventory
TCPFL	Total Cost per Flight Hour
Ti	Titanium
T&M	Time and Materials
TO	Technical Order
TOR, ToR	Terms of Reference
TRL	Technology Readiness Level
TY	Then Year
UPNR	Unit Possessed but Not Reported
U.S., US	United States
USAF	United States Air Force
USG	United States Government
USMC	United Stated Marine Corps
UV	Ultraviolet
V&V	Verification and Validation
WFD	Widespread Fatigue Damage
W/O	Without
WPAFB	Wright-Patterson Air Force Base
WR-ALC, WRALC	Warner-Robins Air Logistics Center

WSR	Weapons System review
WSS	Weapon System Sustainment
WUC	Work Unit Code
Y	Yellow
Yrs	Years

Appendix G: List of References

This reference list is a list of the materials that informed the Panel members' deliberations during the course of this Study. These represent the materials (briefings, papers, articles, etc.) made available to the members of Sustaining Aging Air Force Aircraft into the 21st Century Study during their preparation for and conduct of the Study. Many were provided by outside organizations/individuals that briefed the Study and some were contributed by the Panel members themselves. In general, these materials were provided as background information or as briefings during various fact-finding trips undertaken by the Study Panel members. Many are not available for distribution beyond the Air Force Scientific Advisory Board as they contain classified, export controlled, proprietary, and/or For Official Use Only information.

Notes: The references are listed by author(s) and date (if no date then "n.d."). If no author is cited then the document is ordered by the title of the document.

1st Fighter Wing. (2011, June). F-22 Interfaces. Briefing presented to the SAA Study Panel of the AF SAB during SAB Summer Board at Langley AFB, Hampton, VA.

76 Software Maintenance Group. (n.d.). 76 SMXG Manpower Hours. Briefing slides provided to the SAA Study Panel of the AF SAB during SAB Summer Board at Langley AFB, Hampton, VA.

402 Software Maintenance Group. (n.d.). Summary of Major Software Trends. Information paper provided to the SAA Study Panel of the AF SAB during SAB Summer Board at Langley AFB, Hampton, VA.

AF SLEPS. (n.d.). Briefing slides provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA.

Aguilar, J. (2011, January). AETC Briefing to the SAB on the T-38 Aircraft. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Air Force Fleet Viability Board History. (2005, October). Document extract (Appendices, Section 3.1 only) provided to the SAA Study Panel of the AF SAB.

Air Force Fleet Viability Board. (2007, March). Phase 1: C-130E and H1 Assessment Report. Wright-Patterson AFB, OH: Author. (Note: Document is For Official Use Only and is Proprietary).

Air Force Fleet Viability Board. (2007, December). Phase 2: HC-130P/N Assessment Report. Wright-Patterson AFB, OH: Author. (Note: Document is For Official Use Only and is Proprietary).

Air Force Fleet Viability Board. (2008, September). F-15C/D Assessment Report (Volume 1 of 2). Wright-Patterson AFB, OH: Author. (Note: Document is For Official Use Only and is Proprietary).

Air Force Fleet Viability Board. (2009, May). E-8C Assessment Report. Wright-Patterson AFB, OH: Author. (Note: Document is For Official Use Only and is Proprietary).

Air Force Fleet Viability Board. (2010). Air Force Fleet Viability Board Tri-Fold. Wright-Patterson AFB, OH: Author.

Air Force Fleet Viability Board. (2010, March). T-38C Assessment Report. Wright-Patterson AFB, OH: Author. (Note: Document is For Official Use Only and is Proprietary).

Air Force Fleet Viability Board. (n.d.). Aggregate Risk Process. Information paper provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Air Force Fleet Viability Board. (n.d.). Assessment Priorities. Briefing slide provided to the SAA Study Panel of the AF SAB. (Note: Slide is For Official Use Only).

Air Force Fleet Viability Board. (n.d.). CSAF Tasking: Fleet Assessment Matrix (v3). Spreadsheet provided to the SAA Study Panel of the AF SAB.

Air Force Fleet Viability Board. (n.d.). SAB Question 3 Charts (C-130 Actual vs Schedule PDM). Charts provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Air Force Global Logistics Support Center. (n.d.). Air Force Global Logistics Support Center: The Warfighter's Choice for Air Force Supply Chain Management. Trifold brochure provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Air Force Global Logistics Support Center. (n.d.). Demand Forecast Accuracy. Briefing slide provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Air Force Materiel Command. (2009). Implementing Operational Safety Suitability and Effectiveness (OSS&E) and Life Cycle Systems Engineering (LCSE) (Air Force Material Command Instruction 63-1201 Change I). Wright-Patterson AFB, OH: Author.

Air Force Materiel Command (n.d.). Core and 50/50 Truths Reference Guide. Briefing slides provided to the SAA Study Panel of the AF SAB.

Air Force Research Laboratory. (2003, September). Aircraft Maintenance Intuitive Troubleshooting (AMIT). Information paper provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Air Force Research Laboratory. (n.d.). Aircraft Maintenance Intuitive Troubleshooting (AMIT). Briefing slide provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Air Force Research Laboratory. (n.d.). Sustainment Funding. Briefing slide provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Air Force Special Operations Command. (2011, February). FY10 Mx Man-Hour/Flying-Hour. Briefing slide provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA. (Note: Material is For Official Use Only).

Air Mobility Command. (2011, March). AF Scientific Advisory Bd Visit: Briefing Points/Takeaways. Paper provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Air Mobility Command Directorate of Logistics. (2011, March). AF Scientific Advisory Board Brief. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Aldridge, P. (2001). (2001, July 12). Testimony of Undersecretary of Defense (Acquisition, Technology, and Logistics): Department of Defense FY02 Budget Request for Procurement and Research and Development to House Armed Services Military Procurement Subcommittee and House Armed Services Military Research and Development Subcommittee. [On-line] Available: www.DoD.gov/DoDgc/olc/docs/test01-07-12Aldridge.rtf

Alford, R. (2011, February). GR Sustaining Engineering Issues. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Allen, T., Sowers, K., Gregg, M., & Buckley, K. (2011, January). C-5M (RERP). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Anderson, N. (2011, March). Global Services & Support: B-1 Software Maintenance. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing proprietary information).

Anderson, N. (2011, March). Global Services & Support Overview. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing proprietary information).

Arledge, E. (2011, January). AF/A4L Perspective on Sustainment of Aging Aircraft. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA.

Armstrong, W. (2011, March). Requirements and Planning Council (R&PC) Process. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Babione, J. (2011, February). F-22 Overview. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Babish, C. (2009, September). ASIP View on the Implementation of SHM into USAF Aircraft. Briefing provided to the SAA Study Panel of the AF SAB.

Babish, C. (2011, January). Summary of the 2010 Aircraft Structural Integrity Program (ASIP) Review. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Babish, C. (2011, January). USAF ASIP: Protecting Safety for 52+ Years. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Babot, D., Berodias, G., & Peix, G. (1991). Detection and Sizing by X-ray Compton Scattering of Near-surface Cracks under Weld Deposited Cladding. NDT&E International, 24 (5), 247-251.

Ball, P. (2011, January). AF FVB Fleet Prioritization. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

Barron, D. (2011, April). OO-ALC Integrity Programs. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Bartlett, T. (2011, March). USAF Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing proprietary and copyrighted information).

Belisle, T. (2011, May). Joint Surveillance Target Attack Radar System (Joint Stars). Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing contains Northrop Grumman Proprietary Information and For Official Use Only information).

Bell, R. (2011, May). Northrop Grumman Electronic Systems Aging Aircraft Systems. Briefing provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing contains Northrop Grumman Proprietary information).

Bennett, H., & Rajlich, V. (2000). Software Maintenance and Evolution: A Roadmap. In A. Finkelstien (Ed.), The Future of Software Engineering. New York, NY: ACM Press.

Bergey, C., Gahring, D., & Goolishian, K. (2011, April). MECSIP FSID Website Overview. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Betz, K. (2011, March). AFGSC A4/7. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Boehm, B., Lane, J., Koolmanojwong, S., & Turner, R. (2010). Architected Agile Solutions for Software Reliant Systems. In T. Dingsoyr, T. Dyba, T., & N. B. Moe, (Eds.), Agile Software Development: Current Research and Future Directions (pp. 165-184). Berlin, Germany: Springer.

Boeing Company. (2011, March). B-52H Bomber Fleet Support Program. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing copyrighted information).

Boeing Company. (2011, March). Boeing Services and Support Information: C-17 GSP APU PBL-DPFH Reduction. Briefing slides provided to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing proprietary and copyrighted information).

Boeing Company. (2011, March). KC-135 Tanker Fleet Support Program. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing copyrighted information).

Boeing Company. (2011, May). Airplane Maintenance Programs. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Boeing facility in Tukwilla, WA. (Note: Briefing contains Boeing Proprietary and Boeing Copyright information).

Boeing Company. (2011, May). Enhanced Airworthiness Program for Airplane Systems / Fuel Tank Safety / Design Approval Holder (EAPAS / FTS – DAH): Ensuring the Continued Airworthiness of Airplane Wiring. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Boeing facility in Tukwilla, WA. (Note: Briefing contains Boeing Proprietary information).

Boeing Company. (2011, May). Use of Technology to Speed and Simplify Maintenance of Commercial Aircraft. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Boeing facility in Tukwilla, WA. (Note: Briefing contains Boeing copyrighted information).

Brigance, K. (2011, February). Electronic Warfare/Avionics. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Buczkowski, K. (2011, February). Global Sustainment Technology. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Bullet Background Paper KC-135 Sustainment Issue. (n.d.). Paper provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Burick, R. (2011, February). P-3 Overview: Enabling Operational Effectiveness for Decades to Come. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Burke, L., & Hughes, G. (2011, March). Sustaining Aging Aircraft: DMSMS & Sustaining Engineering. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Burks, B. (2011, January). Depot Maintenance, 50/50, & Data Rights. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Butler, A. (2011, January 19). Fiscal FY12 Could Boost Bomber, F-16, F-15. Aviation Week and Space Technology [On-line]. Available: http://www.aviationweek.com/aw/generic/ story_channel.jsp?channel=defense&id=news/awst/2011/01/17/AW_01_17_2011_p22-282270.Xml&headline=null&next=10

Butler, A. (2011, January 20). USAF Assesses New KC-10 Upgrade Bids. Aviation Week and Space Technology [On-line]. Available: http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=aerospacedaily&id=news/asd/2011/01/20/01.xml&headline=USAF%20Assesses%20New%20KC-10%20Upgrade%20Bids

Buxbaum, P. (2010). Obsolescence Management. Military Logistics Forum, 4 (8).

Calomino, M. (2011, May). T-38. Briefing provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing contains Northrop Grumman Private information).

Cameron, A. (2011, February). F-35 Global Sustainment Overview: Affordable Readiness for the Warfighter. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding

meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Camp, C. (2011, February). KC-135 Executive Summary Cruise. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Castanier, M., Glanovsky, J., Gray, L., Grelotti, R., Harmon, D., Jacobs, L., Littles, J., Morris, R., & Tulpule, S. (2010). Propulsion System Prognosis. Arlington, VA: Defense Advanced Research Projects Agency. (Note: Document is For Official Use Only, Export Controlled, and subject to Limited Data Rights).

Chaston, D. (2011, March). CLS Sustainment Division (GKS) Presentation for Science and Advisory Board Sustaining Aging Aircraft Study. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Chernoff, A. (2010, November 12). FAA Moving to Prevent Aging Aircraft Dangers. [On-line]. Available: http://articles.cnn.com/2010-11-12/travel/fatigue.damage_1_fatigue-damage-fatigue-cracks-faa?_s=PM:TRAVEL11

Classi, C. (2011, May). Strategic Design Refresh Planning for Large-Scale Complex Systems. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA.

Climie, B. (2011, April). Military Airplane Health Management. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Close, K. (2011, January). DoD Appropriation Account Codes. PowerPoint slide provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Wright-Patterson AFB, OH.

Close, K. (2011, January). Integrated Life Cycle Management. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Close, K. (2011, January). Product Improvement: Funding Decision Tree. PowerPoint slide provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Wright-Patterson AFB, OH.

Close, K. (2011, January). Sustaining Aging Aircraft. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA.

Close, K., & Yankel, J. (2011, March). Aircraft Sustainment Definitions and Funding. Briefing slides provided to the SAA Study Panel of the AF SAB.

Collins, E., Donnelly, R., Burgess, B., Sanders, B., & Juby, S. (2011, January). ACC Briefing to SAB. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA. (Note: Briefing classified at the SECRET level with some slides For Official Use Only).

Collins, G. (2011, May). C-32 Auxiliary Fuel Tank Flammability: Flammability Exposure Levels vs. Commercial Auxiliary Tanks. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Federal Aviation Administration facility in Renton, WA. (Note: Briefing contains proprietary information).

Collins, G. (2011, May). FTFR Rule affect on Pre-1992 Airplanes: Airplanes in Passenger Service past 100% Retrofit Compliance Date. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Federal Aviation Administration facility in Renton, WA.

Colvard, M. (2011, February). AFSOC Command Brief. Briefing provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Committee for Advancing Software-Intensive Systems Producibility. (2010). Critical Code: Software Producibility for Defense. Washington, DC: The National Academics Press.

Condron, T. (2011, January). MECSIP Presentation to Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Condron, T. (2011, April). Mechanical Equipment and Subsystems Integrity Program (MECSIP). Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT. (Note: Briefing is For Official Use Only).

Condron, T. (2011, April). MECSIP Activity Planned in 2011. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Condron, T. (2011, April). MECSIP Review Template and Recommended Changes. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Cone, W. (2006). Improving Maintenance Data Collection via Point-of-Maintenance (POMX) Implementation. Unpublished Master's Thesis, Air Force Institute of Technology, Wright-Patterson AFB, OH.

Cosby, L., Crawford, N., Gabriel, R., Patton, R., Selden, R., Shulman, H., & Worch, P. (1994). Life Extension and Mission Enhancement for Air Force Aircraft – Volume II: Panel Reports (SAB-TR-94-01). Washington, DC: Air Force Scientific Advisory Board. (Note: Document is For Official Use Only and is Export Controlled).

Covert, E. (1994). Report of the Ad Hoc Committee on Technical Feasibility of C-141 Service Life Extension Program (SLEP). Washington, DC: United States Air Force Scientific Advisory Board. (Note: Document is For Official Use Only and is Export Controlled).

Covert, E., Cosby, L., Crawford, N., Gabriel, R., Olson, R., Patton, R., Reagan, M., Selden, R., Shulman, H., & Worch, P. (1994). Life Extension and Mission Enhancement for Air Force Aircraft—Volume I: Executive Summary (SAB-TR-94-01). Washington, DC: Air Force Scientific Advisory Board. (Note: Document is For Official Use Only and is Export Controlled).

Craig, B (Ed.). (2005). Corrosion Conscious Design: A Roadmap to Life-Cycle Cost Reduction [Special Issue]. AMPTIAC Quarterly, 9 (3).

Cramer, S., & Covino, B. (Eds.). (2006). ASM Handbook Volume 13C: Corrosion: Environments and Industries. Metals Park, OH: ASM International.

Creating Initial Scheduled Maintenance Plans: Using the MSG-3 Aircraft Systems and Powerplant Analysis Process to Develop an Initial Scheduled Maintenance Plan. (2002, 1st Quarter). Reliability EDGE 3 (1) [On-line]. Available: http://www.reliasoft.com/newsletter/1q20 02/ maintenance.htm

Crowley, F. (2007, August). Fleet Viability Prioritization Model to Air Staff 4-Digits. Presentation materials provided to the SAA Study Panel of the AF SAB. (Note: Presentation is For Official Use Only).

Crowley, F. (2010, November). Scientific Advisory Board Visit. Briefing presented to the SAA Study Panel Chair of the AF SAB. (Note: Document is For Official Use Only).

Crowley, F., & Weidenhammer, W. (2011, January). EC-130H Assessment to USAF Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

D'Carlo, P., & Pesek, Q. (2011, April). F-15 MECSIP Conference 2011. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

DeBusk, B. (2011, February). Joint STARS TSSR DMSMS Working Group Meeting. Briefing provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing is For Official Use Only).

Defense Energy Support Center. (2009). Fact Book. Fort Belvoir, VA: Author.

Defense Science Board. (2000). Report of the Defense Science Board Task Force on Defense Software. Washington, DC: Author.

Delta TechOps. (2011, March). Delta TechOps U.S. Air Force Overview: Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Delta Tech Ops facility in Atlanta, GA.

Dice, J. (2011, March). Mobility Air Forces: Long Range Planning. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Dion-Schwartz, C., & Turner, R. (n.d.). Software-Intensive Systems Producibility Initiative. Briefing provided to the SAA Study Panel of the AF SAB.

Dixon, M. (2005). The Costs of Aging Aircraft: Insights from Commercial Aviation (Doctoral Dissertation, Pardee RAND Graduate School, 2005). Santa Monica, CA: RAND.

Dixon, M. (2006). The Maintenance Costs of Aging Aircraft: Insights from Commercial Aviation. Santa Monica, CA: RAND.

Duffield, S. (2011, January). Technology Insertion. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Eastin, R. (2005, November). Contrasting FAA and USAF Damage Tolerance Requirements. Proceedings of the 2005 USAF ASIP Conference in Memphis, TN.

Eckbreth, A., & Saff, C. (2011, January). Sustaining Air Force Aging Aircraft into the 21st Century. Briefing presented to the AF SAB during the SAB Winter Board Meeting in Crystal City, VA. (Note: Document is For Official Use Only).

Eckbreth, A., & Saff, C. (2011, January). Sustaining Air Force Aging Aircraft into the 21st Century: Study Team Kickoff. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA. (Note: Document is For Official Use Only).

Erbschloe, D. (2011, March). Point Paper on AMC/ST brief to AF Scientific Advisory Board. Point paper provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Erbschloe, D. (2011, March). ST Sustainment Perspective for SAB. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Eviston, M. (2011, January). Extended 1553 High Speed Data Bus. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Exponential Software Growth in Fighters. (2008, May). Chart/Excel data provided to the SAA Panel of the AF Scientific Advisory Board by Lockheed Martin.

F-22 System Program Office. (2010, August). F-22 Software Strategy Analysis. Briefing provided to the SAA Study Panel of the AF SAB. (Note: Briefing is For Official Use Only and distribution of the briefing is restricted).

Fantini, M. (2011, January). Sustaining Air Force Aging Aircraft into the 21st Century. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA. (Note: Briefing classified at the SECRET level with some slides For Official Use Only).

Fecke, T. (2011, January). Propulsion Integrity Program. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Federal Aviation Administration. (2011, May). FAA – USAF SAB Discussion. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Federal Aviation Administration facility in Renton, WA.

Federal Aviation Administration. (2011, May). SAB Sustaining Aging Aircraft Study: Discussion Topics for FAA. Paper with FAA responses to SAB questions presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Federal Aviation Administration facility in Renton, WA.

Fitch, T. (2011, January). Repair Network Integration (RNI) & High Velocity Maintenance (HVM). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Fontana, M. (1986). Corrosion Engineering (3rd Edition). New York, NY: McGraw-Hill.

Forman D., Baty, R. Herzberg, E., Kelly, A., Kumaran, M., & O'Meara, N. (2009, June). The Annual Cost of Corrosion for Air Force Aircraft and Missile Equipment (Report MEC81T2). McLean, VA: Logistics Management Institute.

Foster, W. (1995, June). C/KC-135 System Program Director's Aircraft Sustainment Master Plan. Tinker AFB, OK: Oklahoma City Air Logistics Center.

Furse, C., & Stephenson, J. (2011, April). Live Fault Diagnostics for Wire Systems. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Future Flight Data File Analysis Report (1C-5A-102, 1C-5A-105-1). (2011, April). Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Gallagher, J. (2007, May). A Review of Philosophies, Processes, Methods and Approaches that Protect In-Service Aircraft from the Scourge of Fatigue Failures. Proceedings of the 24th International Committee on Aeronautical Fatigue Symposium, Naples, Italy.

Galorath, D. (2008, October). Software Total Ownership Costs: Development is Only Job One. Journal of Software Technology, 11 (3). [On-line]. Available: http://journal.thedacs.com/issue /47/118

Gann, G. (2011, March). KC-135 SAB. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Gann, G. (2011, March). KC-135 SAB Modifications. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Gebman, J. (2008). Opportunities for Systems Engineering to Contribute to Durability and Damage Tolerance of Hybrid Structures for Airframes. Santa Monica, CA: RAND.

Gebman, J. (2008, April). Challenges and Issues with Further Aging of U.S. Air Force Aircraft. Briefing presented to 11th Joint NASA/FAA/DoD Conference on Aging Aircraft.

Gebman, J. (2009). Challenges and Issues with Further Aging of U.S. Air Force Aircraft: Policy Options for Effective Life-Cycle Management of Resources. Santa Monica, CA: RAND.

Gebman, J., & Paris, P. (1978, June). Probability that the Propagation of an Undetected Fatigue Crack Will Not Cause a Structural Failure (R-2238-RC). Santa Monica, CA: RAND.

Gebman, J., & Shulman, H. (1988). A Strategy for Reforming Avionics Acquisition and Support (R-2908/1-AF). Santa Monica, CA: RAND.

Gebman, J., & Shulman, H. (1988). A Strategy for Reforming Avionics Acquisition and Support: Executive Summary (R-2908/1-AF). Santa Monica, CA: RAND.

Gebman, J., Kim, Y., Calef, K., Chow, J., Cornuet, J., Eisman, M., Hagen, J., Lewis, R., Stanley, W., & Tonkinson, J. (2005, December). Analysis of Alternatives (AoA) for KC-135 Recapitalization (Appendix 1) (RAND Report MG-464-AF). (Note: Document is For Official Use Only and is Proprietary). Santa Monica, CA: RAND.

Gebman, J., McIver, D., & Shulman, H. (1989, January). A New View of Weapon System Reliability and Maintainability (R-3604/2-AF). Santa Monica, CA: RAND.

General Atomics Aeronautical Systems, Inc. (2011, May). General Atomics Aeronautical Systems Delivers Situational Awareness. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at General Atomics facility in Poway, CA.

General Atomics Aeronautical Systems, Inc. (2011, May). Sustaining Aging Aircraft Briefing. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at General Atomics facility in Poway, CA. (Note: Briefing contains For Official Use Only information).

Georgeson, G., Edwards, T., & Safai, M. (2011, May). Boeing Scatter X-ray Imaging (BSXI) System. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Boeing facility in Tukwilla, WA. (Note: Briefing contains Export Controlled and Boeing Proprietary and Boeing copyrighted information).

Gerken, S. (2011, April). Aircraft Wiring Integrity and Life Extension. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Glista, S. (2011, April). High Margin Durability Margin Analysis (HDMA). Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Gonzalez, J. (2011, February). Engineering Directorate Overview. Briefing slides provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Green, S. (2011, January). AFMC Applied Technology Council (ATC) Concept Brief. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Gregg, M. (2011, February). C-5 Galaxy Division. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Gregg, M. (2011, February). C-5 MSG-3 Fleet Implementation. Briefing provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Griffiths, L., Parakh, R., Furse, C., & Baker, B. (2006). The Invisible Fray: A Critical Analysis of the Use of Reflectometry for Fray Location. IEEE SENSORS Journal, 6 (3), 697-703.

Grimsley, F. (2011, January). USAF Airworthiness Process Overview: Presentation to Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Hackett, M. (2011, April). SAB SAA Panel: Sustaining Engineering Issues. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Haley, A. (2011, January). Avionics Integrity Program (AVIP). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Hannan, S. (2009, February). KC-135R/T: Trends in Programmed Depot Maintenance (PDM). Briefing slides provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA. (Note: Briefing slides are For Official Use Only).

Hannan, S. (n.d.). O&M Cost per Flying Hour Drivers: A Historical Analysis. Briefing slides provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA. (Note: Briefing slides are For Official Use Only).

Hansen, M., & Nesbit, R. (2000, November). Report of the Defense Science Board Task Force on Defense Software. Washington, DC: Defense Science Board.

Harrison, J. (2011, April). Airplane Health Management Overview. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT. (Note: Briefing contains Boeing Copyrighted information).

Hebert, G. (2011, April). Scientific Advisory Board A-10 Briefing. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Hermes, E. (2011, January). AFRL Support of Current AF Fleets. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

Hicks, B. (2011, January). T-6. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Hoffman, D. (2011, February). AFMC Update (Transcript of remarks given at the Air Warfare Symposium, Orlando, FL February 17, 2011 by General Donald A. Hoffman, USAF) [On-line]. Available: http://www.afa.org/events/AWS/2011/postOrlando/scripts/AFA-110217-Hoffman.pdf

Hogan, C. (2011, April). ASIP vs MECHSIP vs LGIP. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Hogan, C. (2011, April). Landing Gear Integrity Issue. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Ivey, R., & Heath, R. (2011, April). Implementing MECSIP Through a Reliability Centered Maintenance Program for the Air Force C-130 SPO. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Jansen, R. (2011, February). F-15 Structures Mishap. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Jonason, M. (2011, March). Propulsion Scientific Advisory Board Brief. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Jones, R. (2011, February). Automatic Test Equipment. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Joy, B. (2011, February). Joint STARS Reliability, Maintainability & Availability Review. Briefing provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing is For Official Use Only).

Joyce, J. (2011, February). C-17 February Executive Summary (Feb 10 - Jan 11). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Jurgemeyer, A. (2011, March). Bullet Background Paper on Sustaining Aging Aircraft: Technology. Paper provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Kalpakjian, S., & Schmid, S. (2009). Rapid Prototyping Operations. In Manufacturing Engineering and Technology (6th Edition). Upper Saddle River, NJ: Pearson Educational Publishing.

Kearney, A. (2011, February). Air Force Material Command Enterprise Software Capability Analysis (Capability Data Request – Squadron-Level Data Analysis: WR-ALC). Briefing provided to the SAA Study Panel of the AF SAB. (Note: Distribution of the briefing is restricted).

Keating, E., Snyder, D., Dixon, M., & Loredo, E. (2005). Aging Aircraft Repair-Replacement Decisions with Depot-Level Capacity as a Policy Choice Variable. Santa Monica, CA: RAND.

Keen, A. (2011, January). F-22 Reliability and Maintainability Maturation Program (RAMMP). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Kennedy, M., Baldwin, L., Boito, M., Calef, K., Chow, J., Cornuet, J., Eisman, M., Fitzmartin, C., Gebman, J., Ghashghai, E., Jeff Hagen, J., Hamilton, T., Hildebrandt, G., Kim, Y., Leonard, R., Lewis, R., Loredo, E., Norton, D., Orletsky, D., Perdue, H., Pyles, R., Ramey, T., Roll, C., Stanley, W., Stillion, J., Timson, F., & Tonkinson, J. (2006). Analysis of Alternatives (AoA) for KC-135 Recapitalization: Executive Summary. Santa Monica, CA: RAND.

Kielty, R. (2011, March). 635th Supply Chain Operations Wing Mission Brief. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Kinzie, R. (2002, September). Corrosion Suppression: Managing Internal & External Aging Aircraft Exposure. Proceedings of the 6th FAA/DoD/NASA Aging Aircraft Conference, San Francisco, CA.

Kinzie, R. (2003). Cost of Corrosion. Unpublished paper provided to the SAA Study Panel of the AF SAB.

Klapper, L. (2011, February). Cost Definitions. E-mail provided to the SAA Study Panel of the AF SAB.

Klapper, L. (2011, April). Cost Per Flying Hour Discussion. Briefing presented to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA.

Kobryn, P. (2011, January). AFRL Sustainment Portfolio. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

Koseak, P. (2011, January). T-38s Resurrected as Aggressors for F-22s. Air Foree Times [On-line]. Available: http://www.airforeetimes.eom/news/2011/01/air-foree-t38-aggressors-for-f22s-012311w/

Krasner, H. (2009). Legacy Software Maintenance Improvement: Where is the Payoff?. Briefing slides provided to the SAA Study Panel of the AF SAB. (Notes: Briefing originally presented at the Information Technology Metries and Produetivity Software Best Practices Conferenee, Baton Rouge, LA. Slides are eopyrighted.).

Lapham, M. (2005). Sustaining Software Intensive Systems – A Conundrum. Presentation at the National Defense Industrial Association Systems Engineering Conference, San Diego, CA.

Lapham, M., & Woody, C. (2006, May). Sustaining Software Intensive Systems (CMU/SEI-2006-TN-007). Pittsburg, PA: Software Engineering Institute.

Larkin, M., & Hannan, S. (2008, June). Common Component Cost of Aircraft O&M Cost: Principal Component Analysis Approach. Presentation provided to the SAA Study Panel of the AF SAB. (Note: Presentation is For Offieial Use Only).

Lauderdale, B. (2011, February). F-16 Overview. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Lebron, R., Rossi, R., & Foor, W. (2000). Risk Based COTS Systems Engineering Assessment Model: A Systems Engineering Management Tool and Assessment Methodology to Cope with the Risk of Commercial Off the Shelf (COTS) Technology Insertion During the System Life Cycle. In Strategies to Mitigate Obsolescence in Defense Systems Using Commereial Components (RTO-MP-072 AC/232(SCI-084)TP/31), a compendium of papers and presentations from the NATO Researeh and Teehnology Organization Systems Coneepts and Integration Panel (SCI) Symposium held in Budapest, Hungary, Oetober 23-25 Oetober 2000.

Lepper, R. (n.d.). Airline Study on Aircraft Availability. Washington, DC: United States Air Force Directorate of Logistics (AF/A4L). Presentation materials provided to the SAA Study Panel of the AF SAB.

Lerman, D. (2011, June 2). The High Cost of Waging War on Rust. Bloomberg Businessweek [On-line]. Available: http://www.businessweek.com/magazine/content/11_24 /b4232037277920 .htm

Lincoln, J. (1998). A Structural Assessment of USAF Aging Aircraft (Appendix M.4B). Wright-Patterson AFB, OH: Aeronautical Systems Center (Engineering Direetorate). (Note: Document is For Offieial Use Only).

Lincoln, J. (2002). Report of the Aging Aircraft Technologies Team on USAF Aging Aircraft: Struetures and Meehanieal Subsystems. Wright-Patterson AFB, OH: Aeronautical Systems Center (Engineering Direetorate). (Note: Doeument is For Offieial Use Only).

Lindgren, E. (2011, April). Whole Aireraft Assessment by Nondestructive Evaluation Methods: Past, Present, and Future. Personal observations provided to the SAA Study Panel of the AF SAB. (Note: Document is For Official Use Only).

Linzey, W. (2006). Development of an Electrical Wire Interconnect System Risk Assessment Tool (DOT/FAA/AR-TN06/17). Washington, DC: Federal Aviation Administration.

Lockheed Martin. (2011, May). AF Science Advisory Board Action Item Follow-Up. Briefing slides provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing slides contain Lockheed Martin proprietary information).

Lockheed Martin Aeronautics Company (n.d.). Software Functionality in Acquisition. Briefing provided to the SAA Study Panel of the AF SAB.

Lowas, A. (2011, January). What is Sustainment Engineering?. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Loy-Kraft, G. (2011, April). OO-ALC Technology Insertion Strategy & Execution. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Lyman, S. (2011, January). CAM LRDP Requirements. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Lynch, J., Sundararajan, A., Law, K., Kiremidjian, A., & Carryer, E. (2003). Power-Efficient Data Management for a Wireless Structural Monitoring System. Proceedings of the 4th International Workshop on Structural Health Monitoring, Stanford University, Stanford, CA, (pp. 1177-1184).

Mahlman, L. (2011, February). Global Sustainment Overview: Delivering Operational Effectiveness and Readiness at Best Value. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Majcher, K. (2011, January 20). 10 Technologies to Watch. Aviation Week [On-line]. Available: http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=om&id=news/om/ 2011/01/01/OM_01_01_2011_p24-278622.xml

Majcher, K. (2011, April 11). Aviation Week and Space Technology [On-line]. Available: http://www.aviationweek.com:80/search/articleQuickSearch.do?parameter=displayArticles&keyword=Sustainment+Struggle&reference=xml/awst_xml/2011/04/11/AW_04_11_2011_304815.xml&databaseName=awst&issueDateWT=04/11/2011&publicationName=awst&headline=Pentagon%20Shifts%20Maintenance%20Strategies%20As%20War%20Funding%20

Martin, L. (2004). Developing a Self-Powered, Wireless Damage Detection System for Structural Health Monitoring Applications. Unpublished Master's Thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Martin, L. (2011, February). C-130 Overview: Sustaining Air Force Aging Aircraft into the 21st Century. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Maxwell, M. (2011, January). Strategic Challenges of Force Planning. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA. (Note: Briefing classified at the SECRET level with some slides For Official Use Only).

McCoy, G. (2011, March). The Air Force Global Logistics Support Center: Global Logistics – Warfighter Focus. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

McDonnell Douglas Corporation. (2006, April). Technical Manual, Aircraft Maintenance, Work Unit Code Manual, USAF Series F-15A 73-085 and Up/F-15B 73-108 and Up/F-15C 78-0468 and Up/F-15D 78-0561 and Up/F-15E 86-0183 and Up Aircraft (TO 1F-15A-06, Change 25). (Note: Document is For Official Use Only and is Export Controlled).

McMahon, R. (2011, February). WR-ALC SAB Visit. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

McQuain, B. (2011, January 19). Are We Headed to an Unrecoverable Fighter Jet Gap? The Examiner [On-line]. Available: http://washingtonexaminer.com/blogs/opinion-zone/2011/01/are-we-headed- unrecoverable-fighter-gap

Meng, C. (2008). Computed Image Backscatter Radiography: Proof of Principle and Initial Development. Unpublished Master's Thesis, University of Florida, Gainesville.

Mercer, C. (2011, March). Tinker Today. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Mercer Engineering Research Center. (2010, August). CBM+ Algorithm Development and Validation Update Report (151000-10015-F1). Warner Robins, GA: Author.

Mercer Engineering Research Center. (2011, April). Age Exploration Task (AE) Within Reliability Centered maintenance (RCM). Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Mercer Engineering Research Center. (2011, April). Capturing the Savings / Cost Avoidance Associated with MECSIP. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Merrill, D. (2011, March). USAF Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Mesdaghi, M. (2011, April). Air Force Global Logistics Support Center: 748th Engineering Supply Chain Management Responsibilities. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Miller, E. (2011, March). Director of Propulsion Overview. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Miller, J. (2011, March). AF SAB Sustaining Aging Aircraft Panel Meeting. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Miller, J. (2011, March). Sustaining Engineering Issues. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Mitchell, G. (2011, May). KC-10 CLS Program Perspective. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA.

Montgomery, R. (2011, April). Landing Gear & Secondary Power Systems Review. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT. (Note: Briefing is For Official Use Only).

Moore, D. (2011, March). OC-ALC Technology Insertion Process. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Mousseau, D. (2011, April). Naval Aviation Subsystems Safety Integrity Program (NASSIP) Program Overview and Strategy. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

National Academies of Science (Committee on Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs). (2010, December). Greybeard Assessment of the Sustainment Technology Transition Process. Briefing provided to the SAA Study Panel of the AF SAB.

National Research Council (Committee on Aging of U.S. Air Force Aircraft, Commission on Engineering and Technical Systems). (1997). Aging of U.S. Air Force Aircraft (NMAB-488-2). Washington, DC: National Academies Press.

National Research Council (Committee for Advancing Software-Intensive Systems Producibility). (2010). Critical Code: Software Producibility for Defense. Washington, DC: National Academies Press.

National Research Council National Materials Advisory Board. (2010). Research Opportunities in Corrosion Science and Engineering. Washington, DC: National Academies Press.

National Research Council (Air Force Studies Board). (2011). Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs. Washington, DC: National Academies Press.

National Transportation Safety Board (1989). Aircraft Accident Report: Aloha Airlines, Flight 243, Boeing 737-200, N73711, Near Maui, Hawaii, April 29, 1988 (NTSB/AAR-89/03). Washington, DC: Author.

National Transportation Safety Board (1990). Aircraft Accident Report: United Airlines Flight 232, McDonnell Douglas DC-10-10, Sioux Gateway Airport, Sioux City Iowa, July 19, 1989 (NTSB/AAR-90/06). Washington, DC: Author.

Naval Air Systems Command. (2005). Management Manual: Guidelines for the Naval Aviation Reliability-Centered Maintenance Process (NAVAIR 00-25-403). Patuxent River, MD: Author.

Navarra, K. (2011, January). System Life Cycle Management (SLIM). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Nelson, J., Konoske Dey, P., Fiorello, M., Gebman, J., Smith, G., & Sweetland, A. (1974, October). A Weapon-System Life-Cycle Overview: The A-7D Experience (R-1452-PR). Santa Monica, CA: RAND.

Nelson, R. (1977). Life-Cycle Analysis of Aircraft Turbine Engines (R-2103-AF). Santa Monica, CA: RAND Corporation.

Newman, J. (2008). Aerospace NDT with Advanced Laser Shearography. Proceedings of the 17th World Conference on Nondestructive Testing, Shanghai, China.

Newton, G., & Frazier, W. (2011, January). Naval Aviation Sustainment Overview. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA.

Nguyen, H. (2011, April). C-5 Aging Fleet Integrity and Reliability Management (AFIRM). Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Nieser, D. (2000, May). Effects of Corrosion on C/KC-135 Structural Life and Flight Safety to 2040. Proceedings of the Fourth Joint DoD/FAA/NASA Conference on Aging Aircraft, Saint. Louis, MO.

Northrop Grumman Corporation. (2011, June 3). E-Mail from R. Blickley: Follow-up Action to 2 May Aging Acft Panel Visit. Provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Northrop Grumman facility in Palmdale, CA.

Office of the Joint Chiefs of Staff. (2007). Chairman of the Joint Chiefs of Staff Manual: Operation of the Joint Capabilities Integration and Development System (CJCSM 3170.01C). Washington, DC: Author.

Office of Naval Research. (2009). Naval S&T Strategic Plan: Defining the Strategic Direction for Tomorrow. Arlington, VA: Author.

Ogden Air Logistics Center. (2010, July). CAM Overview FY-7-10 (T-38 FY11 AAIP Funding Bogies). Briefing slide provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, April). A-10 Ten Year Data (A10-03). Spreadsheet provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, April). Cataloging Process for DLA Managed Items. Briefing slides provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, April). Configuration Management Issues for Aging Aircraft. Briefing slides provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, April). How Can SAB Help?. Briefing slides provided to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, April). OO-ALC SBIR Phase IIIs. Document provided to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, April). SAB AI A10-06. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, April). T-38 Fleet CPFH Projection based on AFTOC Historical Data. Briefing slide provided to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (2011, May). Topics to be Discussed During Dr Schmidt's Meeting with ALC SMXG Leadership x4. Document provided to the SAA Study Panel of the AF SAB.

Ogden Air Logistics Center. (n.d.). A10 Action Items. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). A-10 Software Lines of Code Growth. Briefing slide provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). Acronym/Definition List for A-10 SAB Briefing. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). Acronyms used in the T-38 Scientific Advisory Board (SAB) Briefing dated 6 Apr 11. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). AF Scientific Advisory Board Action Items for the F-16. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). ALC GH-02: Deficiency Reports. Briefing slides provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). All-01 F-16 SAB Acronyms. Spreadsheet provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). All-02 Provide Current & Projected Number of Lines of Software Code by A/C Type/Model/Series. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). F-16 SAB Drivers (F-16-020). Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). F-16-014 SAB FSTAR & UPI. Briefing slides provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). Intermittent Fault Detection and Fault Isolation System. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). SAB AI #F-16-019. Document provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). T-38 FY11 AAIP FYDP Update. Briefing slides provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Ogden Air Logistics Center. (n.d.). T-38-003 & 004 SAB Briefing AIs. Briefing slides provided to the SAA Study Panel of the AF SAB after the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Oklahoma City Air Logistics Center. (2010, November). B-52 Flight Mishap History. Paper provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. Available: http://www.afsc.af.mil/shared/media/document/AFD-080114-043.pdf

Oklahoma City Air Logistics Center. (2011, June). 76 SMXG Overview. Briefing provided to the SAA Study Panel of the AF SAB.

Oklahoma City Air Logistics Center. (2011, June). Topics to be Discussed During Dr Schmidt's Meeting with 76 SMXG Leadership. Document provided to the SAA Study Panel of the AF SAB.

Oklahoma City Air Logistics Center. (n.d.). 76 SMXG Manpower History. Briefing slides provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Oklahoma City Air Logistics Center. (n.d.). AI #16-19: B-1. Briefing slides provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Oklahoma City Air Logistics Center. (n.d.). AI #20: NDI Types at OC-ALC. Briefing slides provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Oklahoma City Air Logistics Center. (n.d.). AI #7: Technology Insertion—Successfully Transitioned Projects—Funding Sources. Paper provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Oklahoma City Air Logistics Center. (n.d.). Flowdays FY03-FY10 (Engines). Spreadsheet provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Oklahoma City Air Logistics Center. (n.d.). Oklahoma City Air Logistics Center Action Item Disposition. Document provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Oklahoma City Air Logistics Center. (n.d.). Propulsion Requirements System. Briefing slide provided to SAA Study Panel of the AF SAB after fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK.

Pagett, M. (2011, January). Office of Naval Research Overview. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA. (Note: Document is For Official Use Only).

Parker, J. (2011, May). UK AWACS Whole Life Support Program. Briefing provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing contains Northrop Grumman Proprietary information).

Patel, M. (2011, January). Air Force Process Transformation using Product Lifecycle Management. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Pezzoni, R. (2000). Laser-Shearography for Nondestructive Testing of Large Area Composite Helicopter Structures. Proceedings of the 15th World Conference on Non-Destructive Testing Rome, IT, 15-21 October 2000.

Pillo, R. (2011, May). Continuing Airworthiness of Aging Airplanes & Widespread Fatigue Damage. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Boeing facility in Tukwilla, WA. (Note: Briefing contains Boeing Proprietary information).

Plaga, J. (2011, April). Human Systems Integration for Maintainers. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Plant, R. (2011, January 13). How I Learned the Hard Way that Aging Technology is Expensive. Harvard Business Review [On-line]. Available: http://bx.businessweek.com/u-miami-school-of-bus-admin/view?url=http%3A%2F%2Fc.moreover.com%2Fclick%2Fhere.pl%3Fr3932794151%26f%3D9791)

Power, W. (2011, April). ASV/WII Det 3 Insights on Aircraft Aging for Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at General Atomics facility in Poway, CA. (Note: Briefing is For Official Use Only).

Pyles, R. (1999, February). Congressional Testimony: Aging Aircraft: Implications for Programmed Depot Maintenance and Engine Support Costs (CT-149). Santa Monica, CA: RAND.

Pyles, R. (2003). Aging Aircraft: USAF Workload and Material Consumption Life Cycle Patterns. Santa Monica, CA: RAND.

Q&A with Air Force Officials Regarding Spare Parts. (2011, January 23). The Macon Telegraph (Macon.Com) [On-line]. Available: http://www.macon.com/2011/01/23/1420926/qa-with-air-force-officials-regarding.html

Rapp, R. (1990). Hot Corrosion of Materials. Pure and Applied Chemistry 62 (1), 113-122.

Razniewski, M. (2011, May). MSG-3 Structures Analysis. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Boeing facility in Tukwilla, WA. (Note: Briefing contains Boeing Proprietary information).

Razniewski, M. (2011, May). Special Federal Aviation Regulation 88 (SFAR 88). Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Boeing facility in Tukwilla, WA. (Note: Briefing contains Boeing copyrighted information).

Rector, G. (2010). C-130 Repair, Upgrades Adding to Robins Workload, Credibility. WRWR: The Patriot [Online]. Available: http://warnerrobinspatriot.com/view/full_story/10557564/Article-C-130-repair-upgrades-adding-to-Robins-workload--credibility.

Rehberg, C. (2011, January). Air Force Aging Aircraft: An Old Saga with New Insights?. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA. (Note: Document is For Official Use Only).

Rehberg, C. (2011, April). Examining the Aircraft Industrial Base During Declining TOA: Implications for the USAF & A Way Ahead. Document provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA. (Note: Document is For Official Use Only).

Roehrig, G. (2011, May). B-2 Sustainment. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing contains Northrop Grumman Proprietary Information and For Official Use Only information).

Rogers, K. (2011, June 13). Identify Software Maintenance Trends for AF Scientific Advisory Board (AFSAB). Information paper provided to the SAA Study Panel of the AF SAB during SAB Summer Board at Langley AFB, Hampton, VA.

Rosenfeld, T, Hindle, E., Qui, H., Rigney, J., Eklund, N., Vanstone, R., & Kacprzynski, G. (2009, December). DARPA Engine System Prognosis (ESP) Final Report. Arlington, VA: Defense Advanced Research Projects Agency. (Note: Document is For Official Use Only, Export Controlled, and subject to Limited Data Rights).

Rush, J. (2011, March). Global Transport & Executive Systems. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing proprietary information).

Sandborn, P., & Singh, P. (2002). Electronic Part Obsolescence Driven Product Redesign. Proceedings of the Sixth Joint FAA/DoD/NASA Aging Aircraft Conference, San Francisco, CA, September 16–19 2002.

Sargent, K., & Larsen, J. (2011, January). Enable Robust Design of New Systems. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only and is Export Controlled).

Scaggs, J. (2006, September 27). New System Streamlines Air Force Sustainment Funding. Air Force Material Command Public Affairs Office Article [On-line]. Available: http://www.af.mil/news/story.asp?id=123027864

Schick, D., Hahnlen, R., Dehoff, R., Collins, P., Babu, S., Dapino, M., & Lippold, J. (2010). Microstructural Characterization of Bonding Interfaces in Aluminum 3003 Blocks Fabricated by Ultrasonic Additive Manufacturing. Welding Journal, 89, 105-115.

Schneider, L., Howard, K., Glover, S., Lockner, T., & Dinallo, M. (2005). A New Method for Detecting and Locating Insulation Defects in Complex Wiring Systems. IEEE Electrical Insulation Magazine, 21, 14-28.

Shedlock, D. (n.d.). X-Ray Backscatter Systems: Non-destructive Testing for a Variety of Industrial and Military Applications. Briefing provided to the SAA Study Panel of the AF SAB subsequent to Summer Board.

Shimanek, J. (2011, April). T-38 Mechanical Systems Flight Load Spectra and Fatigue Studies. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Shimanek, J. (2011, April). T-38 MECSIP Approach to Identifying Critical Safety Items. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Smith, J. (2011, March). B-52 Scientific Advisory Board (SAB) Briefing. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Smith, J. (2011, March). E-3 Scientific Advisory Board (SAB) Briefing 8 Mar 11. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Spinney, F. (1998, September). Defense Death Spiral. Archive of Defense Commentaries [On-line]. Available: http://pogoarchives.org/labyrinth/01/05.pdf

Spinney, F. (2002). Defense Death Spiral: Why the Pentagon Plans for the Wrong War. Briefing provided to the SAA Study Panel of the AF SAB.

Springer, D. (2011, January). Computer Systems and Software Integrity Program (CSSIP). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Srivastava, A., Mah, R., & Meyer, C. (2009, November). Integrated Vehicle Health Management Technical Plan (Version 2.03). Washington, DC: Aeronautics Research Mission Directorate, National Aeronautics and Space Administration.

Stargel, D. (2011, January). AFOSR Perspectives on Sustaining Aging Aircraft. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA.

Stevens, K. (2011, January). Air Force Research Laboratory Sustainment Investment. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

Storey, M. (2005, May). Theories, Methods and Tools in Program Comprehension: Past, Present and Future. Proceedings of the 13th International Workshop on Program Comprehension, Saint Louis, MO. Note: also available on-line at: http://www.ptidej.net/teaching/inf6306/fall09/notes/course7/Storey%20-%20Theorie,%20Methods%20and%20Tools%20in%20Program%20Comprehension.pdf

Stroscio, M. (n.d.). Tinker Sustaining Engineering Cases. Paper provided to the SAA Study Panel of the AF SAB.

Sutton, D. (2011, April). F-16 System Program Office. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Sutton, J. (n.d.). Ogden ALC Mission Briefing. Briefing presented to the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT.

Swift, G. (2011, February). Eagle Division AF Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

System Breakdown Structure for the Reporting of Maintenance by Operational Units. (n.d.). Document extract provided to the SAA Study Panel of the AF SAB by RAND.

Technology Insertion into the Legacy Fleet for Energy Efficiency: Terms of Reference. (n.d.). Document provided to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL.

Thompson, M., & Flannery, E. (2011, May). RQ-4 Global Hawk Deep Dive Review. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing contains For Official Use Only information).

Thomson, R. (2011, May). Enterprise Analysis and Cost Optimization System (EACOS) Fleet Availability Process. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA.

Tiffany, C., Gallagher, J., & Babish, C. (2010). Threats to Aircraft Structural Safety, Including a Compendium of Selected Structural Accidents / Incidents (ASC-TR-2010-5002). Wright-Patterson AFB, OH: Engineering Directorate, Aeronautical Systems Center.

Tirpak, J. (2011, February). New Life for Old Fighters. Air Force Magazine 94, (2) 29-33.

Tirpak, J. (2010, June). The Thirty Year Drought. Air Force Magazine, 93, (6) 32-35.

Tribble, G., Peavy, W., Ivey, R., & Flattery, J. (2011, February). Tactical Airlift Division AF Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Tripp, R., McGarvey, R., Van Roo, B., Masters, J., & Sollinger, J. (2010). A Repair Network Concept for Air Force Maintenance: Conclusions from Analysis of C-130, F-16, and KC-135 Fleets. Santa Monica, CA: RAND.

Ulmer, G. (2011, February). C-5 Overview. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

United States Air Force (1995). Avionics/Electronics Integrity (MIL-HDBK-87244 (USAF)). Wright-Patterson AFB, OH: Directorate of Engineering, Aeronautical Systems Center. .

United States Air Force. (1997). Department of Defense Handbook: Mechanical Equipment and Subsystems Integrity Program (MIL-HDBK-1798 (USAF)). Wright-Patterson AFB, OH: Directorate of Engineering, Aeronautical Systems Center. (Note: Document contains Export Controlled information).

United States Air Force. (2002). Department of Defense Handbook: Engine Structural Integrity Program (ENSIP) (MIL-HDBK-1783B). Wright-Patterson AFB, OH: Directorate of Engineering, Aeronautical Systems Center.

United States Air Force. (2003). Department of Defense Handbook: Operational Safety, Suitability, & Effectiveness for the Aeronautical Enterprise (MIL-HDBK-514 (USAF)). Wright-Patterson AFB, OH: Directorate of Engineering, Aeronautical Systems Center.

United States Air Force. (2003). Department of Defense Handbook: Weapon System Integrity Guide (WSIG) (MIL-HDBK-515 (USAF). Wright-Patterson AFB, OH: Directorate of Engineering, Aeronautical Systems Center.

United States Air Force. (2005). Department of Defense Standard Practice: Aircraft Structural Integrity Program (ASIP) (MIL-STD-1530C) (USAF)). Wright-Patterson AFB, OH: Directorate of Engineering, Aeronautical Systems Center.

United States Air Force. (2007). Life Cycle Systems Engineering (Air Force Instruction 63-1201). Washington, DC: Author.

United States Air Force. (2008). Department of Defense Standard Practice: Propulsion System Integrity Program (PSIP) (MIL-STD-3024) (USAF)). Wright-Patterson AFB, OH: Directorate of Engineering, Aeronautical Systems Center.

United States Air Force. (2009). Acquisition and Sustainment Life Cycle Management (Air Force Policy Directive 63-1 and 20-1). Washington, DC: Author.

United States Air Force. (2011). Acquisition and Sustainment Life Cycle Management (Air Force Instruction 63-101, Change 4). Washington, DC: Author.

United States Air Force. (2010). Air Force Science and Technology Strategy. Washington, DC: Author.

United States Air Force. (2010). Equipment Inventory, Status and Utilization Reporting (Air Force Instruction 21-103). Washington, DC: Author.

United States Air Force. (2010). Securing the High Ground: 2010 Combat Air Force Strategic Plan. Washington, DC: Author.

United States Air Force. (2010). USAF Airworthiness (Air Force Policy Directive 62-6). Washington, DC: Author.

United States Air Force. (2011, January). Cost Per Flying Hour. Air Force Directorate of Logistics (AF/A4L) Spreadsheet Briefing provided to the SAA Study Panel of the AF SAB.

United States Air Force. (n.d.). Executive Summary: Aircraft Accident Investigation F-15C, T/N 80-0034, Lambert Field IAP, Missouri, 2 November 2007 (20071102KSTL002A). Available: http://www.aviationweek.com/media/pdf/MO%20F-15C%20AIB%20Executive%20Summaries.pdf

United States Air Force Directorate of Studies and Analyses (AF/A9). (2009, June). Summary Analyses on Tanker Recapitalization. Briefing slides provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA. (Note: Briefing slides are For Official Use Only).

United States Air Force Directorate of Studies and Analyses (AF/A9). (n.d.). Aging Aircraft Analyses. Briefing slides provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA.

United States Air Force Directorate of Studies and Analyses (AF/A9). (n.d.). DPEM&CLS Cost vs Time. Briefing slides provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA. (Note: Briefing slides are For Official Use Only).

United States Air Force Software Technology Support Center. (2003). Guidelines for Successful Acquisition and Management of Software-Intensive Systems: Weapon Systems, Command and Control Systems, and Management Information Systems (Condensed Version 4.0). Ogden Air Logistics Center Hill AFB, UT: Author.

United States Army. (2007, December). CBM+ Roadmap. Fort Belvoir, VA: U.S. Army Logistics Innovation Agency.

United States Department of Defense. (1992, May). Operating and Support Cost-Estimating Guide. Washington, DC: Office of the Secretary of Defense Cost Analysis Improvement Group.

United States Department of Defense. (1993). Department of Defense Handbook: Airworthiness Certification Criteria (MIL-STD-516B). Wright-Patterson AFB, OH: Engineering Directorate, Aeronautical Systems Center.

United States Department of Defense. (1998). Model Designation of Military Aerospace Vehicles (DoD 4120.15-L). Springfield, VA: National Technical Information Service.

United States Department of Defense. (2000, February). Department of Defense Standard Practice for System Safety (MIL-STD-882D). Wright-Patterson AFB, OH: Air Force Material Command.

United States Department of Defense. (2001, September). Quadrennial Defense Review Report. Washington, DC: Author.

United States Department of Defense. (2006). Department of Defense Instruction 8115.02: Information Technology Portfolio Management Implementation. Washington, DC: Author.

United States Department of Defense. (2006, February). Quadrennial Defense Review Report. Washington, DC: Author.

United States Department of Defense. (2007). Department of Defense Instruction 4151.20: Depot Maintenance Core Capabilities Determination Process. Washington, DC: Author.

United States Department of Defense. (2008). Condition Based Maintenance Plus DoD Guidebook. Washington, DC: Author.

United States Department of Defense. (2008). Department of Defense Instruction 5000.02: Operation of the Defense Acquisition System. Washington, DC: Author.

United States Department of Defense. (2008). Military Specification: Airplane Strength and Rigidity, Vibration, Flutter, and Divergence (MIL-A-8870C(AS)). Lakehurst, NJ: Aircraft Division, Naval Air Warfare Center.

United States Department of Defense. (2009). DoD Financial Management Regulation (Volume 14). Washington, DC: Author.

United States Department of Defense. (2009). Draft Department of Defense Standard Practice: Avionics Integrity Program (AVIP) (MIL-STD-1796A (USAF)). Wright-Patterson AFB, OH: Engineering Directorate, Aeronautical Systems Center.

United States Department of Defense. (2010). Department of Defense Standard Practice: Mechanical Equipment and Subsystems Integrity Program (MIL-STD-1798B). Wright-Patterson AFB, OH: Engineering Directorate, Aeronautical Systems Center.

United States Department of Defense. (2010, February). Aircraft Investment Plan: Fiscal Years (FY) 2011-2040. Washington, DC: Author.

United States Department of Defense. (2011, March). Aircraft Procurement Plan Fiscal Years (FY) 2012-2041. Washington, DC: Author.

United States General Accounting Office. (2002, January). Aviation Safety: FAA and DOD Response to Similar Safety Concerns (GAO-02-77). Washington, DC: Author.

United States Government Accountability Office. (2010, December). Defense Management: DOD Needs to Monitor and Assess Corrective Actions Resulting from Its Corrosion Study of the F-35 Joint Strike Fighter (GAO-11-171R). Washington, DC: Author.

United States Government. (n.d.). United States Code (Extract): Title 10, Subtitle A, Part IV, Chapter 146, Para 2464, Core logistics Capabilities). Washington, DC: Government Printing Office. Extract provided to the SAA Study Panel of the AF SAB.

Van Oss, D. (2002, September). Avionics Acquisition, Production, and Sustainment: Lessons Learned -- The Hard Way. NDIA 5th Annual Systems Engineering Conference, Tampa, FL.

Vaughn, J. (2011, March). B-1 Bomber SAB. Briefing to the SAA Study Panel of the AF SAB during fact-finding meeting at Oklahoma City Air Logistics Center, Tinker AFB, OK. (Note: Briefing is For Official Use Only).

Voevodin, N., Buhrmaster, D., Balbyshev, V., Khramov, A., Johnson, J., & Mantz, R. (2005). Non-Chromated Coating Systems for Corrosion Protection of Aircraft Aluminum Alloys. Paper presented at the 2005 Tri-Service Corrosion Conference November 2005, Orlando FL.

Wagner, G. (2011, April). Briefing to MECSIP. Briefing provided to the SAA Study Panel of the AF SAB after the MECSIP Conference at Hill AFB, UT.

Wagner, J. (2011, February). U-2 Overview. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Lockheed Martin facility in Marietta, GA. (Note: Briefing contains Lockheed Martin proprietary information).

Wallace, J. (2011, March). AMC POM Process: FY13-17 POM. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Scott AFB, IL. (Note: Briefing contains For Official Use Only information).

Walsh, M. (2008, January). Building the Program Budget. Fort Belvoir, VA: Defense Acquisition University. Teaching Note provided to the SAA Study Panel of the AF SAB at fact-finding meeting at Wright-Patterson AFB, OH.

Ware, R. (2011, April). Mishap Prevention for Acquisition and Sustainment Engineers. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Warner-Robins Air Logistics Center. (2010, November). F-15 Full Scale Fatigue Test Data. Boeing spreadsheet provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Warner-Robins Air Logistics Center. (2010, November). F-15 Full Scale Fatigue Test Schedule (Project: Schedule_FSFT_2009_0611C). Provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Warner-Robins Air Logistics Center. (2011). 402 SMXG Manpower and Production, FY03-FY11. Briefing slide provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Warner-Robins Air Logistics Center. (2011). A/C Age Vs Mx Man Hours. Briefing slide provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Warner-Robins Air Logistics Center. (2011). C-130 Engineering Assistance Requests. Briefing slides provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Warner-Robins Air Logistics Center. (2011). EW Top 10 MICAPS. Briefing slides provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Warner-Robins Air Logistics Center. (2011). Mercer Engineering Research Center (MERC) CBM+ Algorithm Correlations. Briefing slides provided to the SAA Study Panel of the AF SAB after fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Warner-Robins Air Logistics Center. (2011, May). 402 SMXG Organizational Demographics. Chart provided to the SAA Study Panel of the AF SAB.

Warner-Robins Air Logistics Center. (2011, May). 402 SMXG Personnel Summary (a/o 2 May 2011). Spreadsheet provided to the SAA Study Panel of the AF SAB.

Warner-Robins Air Logistics Center. (2011, May). 402 SMXG Software Growth. Spreadsheet provided to the SAA Study Panel of the AF SAB.

Warner-Robins Air Logistics Center. (2011, May). Demographics Profile for AFMC Civilians at WR-ALC 402 Maintenance Wing. Document provided to the SAA Study Panel of the AF SAB.

Warner-Robins Air Logistics Center. (2011, June). Topics to be Discussed During Dr Schmidt's Meeting with ALC SMXG Leadership x3. Document provided to the SAA Study Panel of the AF SAB.

Warner-Robins Air Logistics Center. (n.d.). SMXG Software Capability. Briefing slide provided to the SAA Study Panel of the AF SAB.

Westbrook, K. (2011, April). Systems Integrity. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

Westwood, D. (2011, February). AFMC Workload Distribution (50/50) Reporting Process. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Wright-Patterson AFB, OH.

Wetzel, J. (2011, January). AF FVB Aging Aircraft Theory. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

Wetzel, J. (2011, January). AF FVB Cross-Cutting Observations. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

Wetzel, J. (2011, January). Scientific Advisory Board Visit. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB. Briefing presented to the SAA Study Panel of the AF SAB during fact finding meeting at Wright-Patterson AFB. (Note: Briefing is For Official Use Only).

Wetzel, J. (2011, April). AF FVB Briefing to MECSIP Conference. Briefing provided to the SAA Study Panel of the AF SAB after the Mechanical Equipment and Subsystems Integrity Program Conference at Hill AFB, UT.

White, J. (2011, January). ASC/EN Opening Remarks: USAF Scientific Advisory Board Sustaining Aging Aircraft Meeting. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Whittington, R. (2011, March). C-17 Globemaster III Sustainment Partnership (GSP). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at the Boeing facility at Saint Louis, MO. (Note: Briefing contains Boeing proprietary information and is Export Controlled).

Wiley, V. (2008, May.). Impacts of Inflation on Total Obligation Authority (TOA). Briefing slides provided to SAA Study Panel of the AF SAB at fact-finding meeting in Crystal City, Arlington, VA. (Note: Briefing slides are For Official Use Only).

Winkelman, A., Svedberg, E., Schafrik, R., & Duquette, D. (2011). Preventing Corrosion from Wearing Our Future Away. Advanced Materials and Processes, 169, (3), 26-31.

Wolfe, D. (2006, June). Hot Section Corrosion for Gas Turbine Engines. [On-line]. Available: http://www.arl.psu.edu/documents/D_Wolfe_Hot%20Corrosion%20Poster%20(7_21_06)_MOD1.pdf

Won, I. (2011, May). FAA – USAF SAB Discussion: FAA Background Information. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Federal Aviation Administration facility in Renton, WA.

Woodman, T. (2011, April). T-38 Scientific Advisory Board (SAB) Briefing. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting at Ogden Air Logistics Center, Hill AFB, UT. (Note: Briefing is For Official Use Only).

Worley, R. (2011, January). Air Force Programming Process: Scientific Advisory Board. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA.

Yelverton, S. (2011, January). F-16 Division Service Life Extension Program (SLEP). Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Wright-Patterson AFB.

Young, J. (2008, July 21). [Department of Defense] Reliability, Availability, and Maintainability Policy. Washington, DC: Office of the Undersecretary of Defense.

Young, R. (2011, January). NASA Research Relevant to Aircraft Sustainment. Briefing presented to the SAA Study Panel of the AF SAB during the SAB Winter Board Meeting in Crystal City, VA.

Young, R., & Rohn, D. (n.d.). Aviation Safety Program: Aircraft Aging & Durability Project (Technical Plan Summary. Washington, DC: National Aeronautics and Space Administration.

Zahiri, F. (2011, February). WR-ALC Sustainment Technology Needs. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Zortman, J., & Whalen, K. (2011, May). USAF Scientific Advisory Board Sustaining Air Force Aging Aircraft into the 21st Century Presentation. Briefing presented to the SAA Study Panel of the AF SAB at fact-finding meeting at Northrop Grumman facility in Palmdale, CA. (Note: Briefing contains Northrop Grumman Proprietary Information).

Zwitch, R. (2011, February). 402 SMXG Mission Briefing. Briefing presented to the SAA Study Panel of the AF SAB during fact-finding meeting at Warner-Robins Air Logistics Center, Robins AFB, GA.

Zwitch, R. (2011, June). 402 SMXG Mission Briefing. Briefing provided to the SAA Study Panel of the AF SAB.

Appendix H: Initial Distribution

Air Force Leadership

SAF/OS – Secretary of the Air Force
AF/CC – Chief of Staff of the Air Force
SAF/US – Under Secretary of the Air Force
AF/CV – Vice Chief of Staff of the Air Force

Air Force Secretariat and Air Staff

SAF/AQ – Assistant Secretary (Acquisition)
SAF/IE – Assistant Secretary (Installations, Environment, and Logistics)
SAF/CIO A6 – Office of Warfighting Integration and Chief Information Officer
AF/CVA – Assistant Vice Chief of Staff
AF/RE – Chief of the Air Force Reserve
AF/SB – Military Director of the Scientific Advisory Board
AF/ST – Chief Scientist of the Air Force
AF/A2 – DCS Intelligence, Surveillance, and Reconnaissance
AF/A3/5 – DCS Air, Space, and Information Operations, Plans and Requirements
AF/A4/7 – DCS Logistics, Installations, and Mission Support
AF/A8 – DCS Strategic Plans and Programs
AF/A9 – Director of Studies and Analyses, Assessments, and Lessons Learned
AF/A10 – Director of Strategic Deterrence and Nuclear Integration
NGB/CF – Chief of the Air National Guard

Air Force Major Commands

ACC – Air Combat Command
AETC – Air Education and Training Command
AFGSC – AF Global Strike Command
AFMC – AF Materiel Command
AFRC – AF Reserve Command
AFSPC – AF Space Command
AFSOC – AF Special Operations Command
AMC – Air Mobility Command
PACAF – Pacific Air Forces
USAFE – US Air Forces Europe

Other Air Force Elements

AF Fleet Viability Board
AF Life Cycle Management Center
AF Research Laboratory

- AF Office of Scientific Research
- AFRL/RB/RX/RZ

AF Sustainment Center
- Ogden Air Logistics Complex
- Oklahoma City Air Logistics Complex
- Warner Robins Air Logistics Complex

Combatant and Regional Commands

US Central Command
US European Command
US Joint Forces Command
US Northern Command
US Pacific Command
US Southern Command
US Special Operations Command
US Strategic Command
US Transportation Command

Other DoD and Service Advisory Boards

Army Science Board
Defense Policy Board
Defense Science Board
Naval Research Advisory Committee
Naval Studies Board

Executive Office of the President

National Security Council

Office of the Secretary of Defense and Defense Agencies

Under Secretary of Defense (Acquisition, Technology, and Logistics)
- Assistant Secretary of Defense (Logistics and Materiel Readiness)
- Assistant Secretary of Defense (Research and Engineering)
- Deputy Undersecretary of Defense (Science and Technology)
- Deputy Assistant Secretary of Defense (Manufacturing and Industrial Base Policy)
- Director, Defense Procurement and Acquisition Policy
- Defense Advanced Research Projects Agency
- Defense Logistics Agency

Other Military Services

Assistant Secretary of the Army (Acquisition, Logistics, and Technology)
Assistant Secretary of the Navy (Research, Development, and Acquisition)
Naval Air Systems Command
Office of Naval Research

Joint Chiefs of Staff

Chairman, Joint Chiefs of Staff
Vice Chairman, Joint Chiefs of Staff
Joint Chiefs of Staff, Director for Intelligence (J–2)
Joint Chiefs of Staff, Director for Operations (J–3)
Joint Chiefs of Staff, Director for Logistics (J-4)
Joint Chiefs of Staff, Director for Strategic Plans and Policy (J–5)
Joint Chiefs of Staff, Director for Joint Force Development (J–7)
Joint Chiefs of Staff, Director for Force Structure, Resources, and Assessment (J–8)

Libraries and Data Repositories

Air Force Institute of Technology Library
Air University Library
Defense Technical Information Center
Library of Congress
National Defense University Library
Pentagon Library
US Air Force Academy Library
US Army Command and General Staff College
US Army War College
US Marine Corps Command and Staff College
US Military Academy Library
US Naval Academy Library
US Naval War College

(This Page Intentionally Left Blank)

REPORT DOCUMENTATION PAGE			*Form Approved* *OMB No. 0704-0188*

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and manipulating the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	1 August 2011	Final, January 2011 – August 2011

4. TITLE AND SUBTITLE	5. FUNDING NUMBERS
Sustaining Air Force Aging Aircraft Into the 21st Century	
6. AUTHORS: Dr. Alan Eckbreth (Chair), Mr. Charles Saff (Vice Chair), Mr. Kevin Connolly, Mrs. Natalie Crawford, Dr. Chris Eick, Prof. Mark Goorsky, Mr. Neil Kacena, Prof. David Miller, Dr. Robert Schafrik, Dr. Douglas Schmidt, Prof. Daniel Stein, Prof. Michael Stroscio, Prof. Gregory Washington, Dr. John Zolper	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) HQ USAF/SB 1180 AF PENTAGON RM 5E815 WASHINGTON, DC 20330-1180	8. PERFORMING ORGANIZATION REPORT NUMBER SAB-TR-11-01
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) SAF/OS, AF/CC 1670 AIR FORCE PENTAGON WASHINGTON, DC 20330-1670	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for Public Release, Distribution Unlimited**	12b. DISTRIBUTION CODE **A**

ABSTRACT

As many of its fleets of legacy aircraft types are kept in service well beyond their planned services lives (sometimes in age, sometimes in usage, sometimes both), the United States Air Force (USAF) faces numerous engineering and resource challenges for the continued, cost-effective sustainment of those aging systems. This report details the recommendations made by the USAF Scientific Advisory Board's Sustaining Aging Aircraft (SAA) Study to best position the Air Force to meet those challenges.

The SAA Study Panel visited a cross section of military and commercial aircraft maintenance organizations to assess sustainment practices and identify technologies that can extend system life and ease maintenance costs. The Study identified specific aircraft systems, in addition to structures and engines, that contribute to safety, availability, and effectiveness for aging aircraft; examined commercial practices in airlines, air freight services, and other industries, and evaluated how they might be applied to meet USAF needs; and identified technology needs and technology approaches that can be applied or developed to extend life or ease maintenance of these aircraft systems, while facilitating future adaptations and performance enhancements of the aircraft.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Aging Aircraft, Aircraft Availability, Aircraft Structural Integrity Program, ASIP, Avionics Integrity Program, AVIP, Computer Systems and Software Integrity Program, CSSIP, Diminished Manufacturing Sources, Fleet Viability Board, FVB, laser shearography, Mechanical and Subsystems Integrity Program, MECSIP, Non Destructive Inspection, Propulsion Systems Integrity Program, PSIP, Sustainment, X-Ray backscatter	234 16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Public Release

(This Page Intentionally Left Blank)